Science and Technology in China
Supplementary Reading

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Abstract

In the twenty-first century, science and technology are becoming an increasingly important facet of modernisation for China, in driving first an industrial and then an innovation economy, with major impacts on improving livelihood and in geopolitical competition.

However, the path to the present, as well as the prospects going forward, are by no means straightforward. This lecture begins with some philosophical traditions that have shaped the ways of thought. Much as the early inventions (especially the Four Great Inventions) of pre-modern China are often presented with pride, these advances were principally technological rather than scientific in the modern sense. This evaluation prompts the Needham question: why did modern science fail to emerge in China — a question better understood through its obverse: why (and how) did modern science emerge in Europe. The development of mathematics and astronomy in traditional China is contrasted with the case of Europe, since these subjects played pivotal roles in the birth of modern science.

Shortfalls were already evident in the late Ming and early Qing, when aspects of modern science (in its infancy) were brought to China by missionaries. By the mid-19th century, with military defeats starting with the Opium War, (relative) technological weakness became a motif in Chinese history. Efforts to catch up have been intertwined with political and social reforms, and impeded by invasion as well as internal turmoils.

Two recent periods deserve attention: achievements in a few centrally directed projects starting in the 1960s, and advances across a broad front since about 1980. Two contrasting narratives invite reflection and debate: a rosy view that stresses the astonishing rate of recent advances especially in technology, versus a more cautious assessment that points to the less impressive record in basic science, especially when calibrated to the scale of the population.

Foreword

These notes are written for a module on science and technology within a course *Understanding China* to be offered online to all CUHK students, starting in the academic year 2022–23. This module is intended to occupy about two hours.

There will be three versions to these notes. **Version A** here is meant as my own learning journal as I gather, organise and digest the material, and is made available as supplementary reading for students who want to learn more. An abridged **Version B** will constitute the required reading accompanying the online lecture; a Chinese translation is also available. A further trimmed **Version C** will form the speaking script. The present version, by its nature, must err on the side of being inclusive (and therefore somewhat diffuse); it is hoped that the online lecture will be able to project sharper thematic emphases. As material for a general education course, there is no claim to originality, except for personal views in a small number of places.

Although the primary purpose is to help students gain some understanding of *contemporary* China, that can only be attempted if there is an appreciation of how the present came to be; thus a historical approach is adopted. Here are some possible questions one may have, in linking the past to the present. Is the contrast (if not contradiction) between enviable technological advances and much less impressive basic science a consequence of ancient philosophical traditions and sociological values? Is the emphasis on large projects related to a perceived need to assert national integrity and dignity, as response to a century of foreign encroachment? More generally, learning about the past is a good way to start thinking about the future.

Of course, a two-hour lecture cannot begin to cover all the issues of interest. Necessarily a selection has to be made. Instead of a bland overall survey, examples throughout the ages are presented in some detail. Choices are made to illustrate what I regard as general and significant trends, and are of course also influenced by my own interest and the limits of my knowledge.

I would regard the lecture as successful if students would begin to ask questions, and start to read and find out more — and, through the window of science and technology, gain a better and more nuanced understanding of China today.

Because these lectures are to be made available to all CUHK students, including international students, the notes are written in English, especially since science and technology is, in the last analysis, a subject of universal concern. The treatment of Chinese names is explained in Appendix A, and a glossary of names and terms, referenced to the Chinese original, is appended at the end of the manuscript.

Acknowledgment

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Gratitude goes to Prof Wong Suk-Ying, who was in charge of student exchange, for giving me the impetus to move beyond a long-standing but admittedly casual interest in the subject. It was in 2018 that she mooted the idea of putting together such a course to serve, in the first instance, exchange students from Stanford expected to come to CUHK. The course was accordingly developed and has been offered for three cycles, in the fall terms of 2019, 2020 and 2021. Events beyond anyone's control meant that only a small number of students in that original target group were able to join the course, and only in 2021. Nevertheless, the course was well received by CUHK students registered within the category of Chinese Cultural Heritage in University General Education. The dual-listed course was placed within the responsibility of the Centre for China Studies, and I thank Prof Jan Kiely and the office staff for support. In particular, thanks go to Ms Yang Yiwei, who acted most enthusiastically and capably as TA in 2020 and 2021.

The notes that follow owe much to fellow teachers in that course, and in many places draw heavily on their lectures. In this category I must especially thank Dr FC Chen, who, unlike me, is a real expert on this subject. The course design in particular relied much on his advice. The other teachers include Dr KM Pang, Prof CT Lai, Prof Jiang Yuanan and Prof Fred Cheung, as well as Prof CA Daniels from HKUST. Not all of the topics they covered could be brought within a two-hour lecture; but my understanding of the topic as a whole has been enhanced through their lectures and their writing. More specific acknowledgements can be found in those sections that draw from their parts of the course.

In writing up these notes, I have been especially helped by Dr KM Pang and also Dr WH Wong, in pointing me to sources, correcting some of my mistakes, in proofreading and in the graphics (including graphics for the video recordings). Dr FC Chen, Prof Fred Cheung, Prof Thomas Lee and Prof YS Leung have given valuable input to the manuscript. Prof Xie Zuowei, Prof MC Chu and Prof Dennis Lo have kindly commented on specific portions.

Turning the material into an online lecture with audio-visual bells and whistles is an arduous task, and one which those of us brought up to think of the written word (and the printed page) as the default medium of academic discourse do not find at all easy. I am most grateful to the e-learning support team: Ms Judy Lo and her colleagues Ms Pui Lam So, Mr Rudi Chow from ITSC, and Ms Rita Dong from CLEAR. Dr KM Pang and Dr WH Wong have kindly agreed to take charge of the related student assessment.

It has been several months' work in 2021 and 2022, and the manuscript seen in the ensuing pages would not have been possible without all the help and inspiration so graciously offered. Responsibility for any remaining errors, and for opinions expressed or implied, is mine.

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1 Beginning with the present

If one looks at the science and technology scene around the world today, it is evident that China has gained a leading position in a few domains: 5G, high-speed trains, mobile payments, steel and aluminium production, number of STEM graduates. In many other domains, China is among the few countries at the top: space exploration, nuclear energy, supercomputers, artificial intelligence, manufacturing based on mid-tier technology (e.g., automobiles), publications in top-tier journals, the number of patents, vaccine innovation and production. In several high-end enterprises, China is not yet in the top league: precision engineering, high-quality steel, high-end silicon chips and the tools for their production, civilian aviation,[1] and outstanding achievements in the basic sciences — the last being often remarked. Of course, for all quantitative indicators the per capita performance is less impressive.

Nevertheless, China is now undoubtedly one of the strongest contributors to global science and technology —— so much so that there are nefarious machinations to frustrate the rise of Chinese technology.

The achievements are on the whole fairly recent. They form an important element in the national strategy for modernisation and the goal of prosperity; and they support a positive outlook for the future. Towards the end of this lecture we shall come back to the recent decades and also try to think about the future. But to do so, it is necessary to first look back and understand how we have arrived at the present scene.

2 Some markers in history

There have been huge ups and downs over the course of millennia: times when China had led the world, and times when China had fallen much behind. A few historical periods serve as important markers in this tale.

Circa 1840

It is only necessary to go back some 180 years, to about 1840, for a stark contrast. The Opium War (starting 1839) is usually taken to be the watershed that demarcates the beginning of modern Chinese history (*jindaishi*).[2] The defeats at the hands of relatively small foreign forces were the first of many that made it impossible to ignore the fact of Chinese technological (and therefore military) inferiority —— and started a wave of anguished introspection, fierce debates and bold efforts (many of which turning out to be ill-fated, too little or too late) to embark on a path of modernisation across all fronts, including

[1] With the C919 coming into commercial use, China will be third after the US and the European consortium behind Airbus, but with key components still relying on foreign suppliers.

[2] This demarcation is the usual one adopted in China. Some Western scholars place the start of the modern Chinese history at the time of the Ming–Qing transition.

science and technology. For us here in Hong Kong, the Opium War is especially a historical event not to be forgotten.

The growth of science and technology since then has been wrought with difficulties (as part and parcel of the challenges across many fronts). Nevertheless, foundations were laid from about 1900, and growth has been surprisingly robust in the last four decades; this tale will occupy us in the later parts of this lecture.

The scientific and technological superiority of the West had in fact become apparent to knowledgeable observers a century and a half earlier. Emperor Kangxi (1654–1722) had already come into contact with Western science and technology, mainly through ideas and products brought by European missionaries (see Section 8). Among the gadgets introduced were mechanical clocks, perhaps dismissible as minor curiosities; among the ideas were more accurate astronomical tables and predictions, which had to be taken seriously since heaven and its mandate were central to the legitimacy of empire.[3] The missionaries also brought accurate maps, including knowledge of the New World and the fact that the Earth is round.

One is then led to ask: Why was China so backward scientifically in early Qing and indeed late Ming, compared to the West? Or, as Needham and others (Goodman, 2008) famously queried: Why did modern science fail to develop in traditional China? This kind of question misleadingly directs attention to China itself in trying to explain what did *not* happen. A criticism of Goodman quoted Sivin (2017) as follows:

> If we seek certainties about the long hiatus within Chinese science, we are likely to be disappointed: What did happen was the emergence of early modern science in Europe. It is Europe that needs to be understood.
>
> (Spence, 2008)

Per capita GDP in Europe started to rise dramatically just as the 18th century unfolded (Broadberry et al., 2015), from a base that was at the time roughly on par with China. For China, there was no similar break until about 1950 (Maddison, 2018). The economic surge in Europe signified a new era, some would even say the start of modernity, a phenomenon that invites attention. The explanation lies in the Scientific Revolution and the Industrial Revolution.[4] The Scientific Revolution spanned several centuries, but an iconic work would be Newton's *Principia* of 1687. Thus, to understand why China was (relatively) backwards in the 18th and 19th centuries, one has to first gain some appreciation of the Scientific Revolution in the West, and indeed of its possible roots in the ancient as well as medieval European intellectual tradition.

[3] The pair of examples are selected for a reason: the idea of a *clockwork universe* arising from Newtonian mechanics was central to the Scientific Revolution.

[4] The latter arguably depending on the former as a necessary if not sufficient condition.

Circa 1300

However, Chinese science and especially Chinese technology had not always lagged behind Europe. The chronicles of Marco Polo (c. 1300), describing what he saw in the court[5] and in some major cities in the Yuan dynasty (1271–1368), provide useful clues for comparison. The chronicles recorded such grandeur and opulence that his readers were awed, sometimes incredulous. Although Marco Polo did not write much about science and technology as such, the level of craftmanship and technology could be inferred from the prosperity. There was also an interesting passage about the use of coal, apparently not yet (widely) known in Europe.

From antiquity

What sort of science and technology supported the advanced civilisation witnessed by Marco Polo? A good source is *Mengxi Bitan* (*Dream Pool Essays*) of Shen Kuo (c. 1088), with many interesting examples in its section on science.

For this early period, science and technology were two largely separate spheres of activity: progress in technology and in economic production relied little on basic science. Therefore we shall start with brief surveys of two strands: (1) a sketch of the philosophical traditions that shaped the way that nature was viewed and therefore the way that science would be pursued, and (2) an introduction to some early inventions, especially the so-called Four Great Inventions.

3 Philosophical traditions

What can be said about traditional Chinese philosophy and culture, in so far as these have either facilitated or frustrated the growth of science, or steered it in particular directions?

Simplistic characterisation

It has been said (Feng Youlan, quoted in Mote, 1972) that Chinese agrarian society was concerned with "real values rather than abstract concepts", implying that this was not favourable to the development of basic science. To go beyond such a broad and necessarily simplistic assessment, it will be useful to survey several major schools of philosophy.

Confucianism

Confucianism, the most influential philosophy over much of Chinese history, is principally (if not exclusively) concerned with ethics and society, with little

[5] A note of interest during the COVID pandemic: Marco Polo saw that the attendants at palace banquets wore scarfs over their mouths for hygienic reasons.

attention to understanding nature. Some indirect influences are mostly negative. (1) Confucian respect for elders comes with the habit of not doubting (let alone challenging) what a teacher might say. (2) Craftsmen and merchants commanded little esteem in Confucian society, but would be key drivers of the Industrial Revolution and the rise of capitalism in Europe. (3) In a broader sense, Confucianism was essentially conservative, with a belief that the golden age for humanity was in the past — an attitude not supportive of scientific progress. The sentiment was not uniquely Chinese; indeed the rise of science in Europe was both the cause and the consequence of a change in mindset that marked the dawn of modernity: that there should be progress towards a better future in this life.

It is therefore no surprise that the leaders of the May Fourth Movement (1919) touted "Mr Science" and "Mr Democracy" as its standard-bearers, and at the same time tried to throw off some of the shackles of Confucianism.[6]

Daoism

Daoism[7] includes two distinct but intertwined strands: the Daoist philosophy (*daojia*) and the Daoist religion (*daojiao*). The word Dao simply means "the way", the origin from which everything derives.

Daoist philosophy can be traced to Laozi and Zhuangzi, who straddled Confucius in time. Laozi is known through the short *Daodejing*. Zhuangzi was an irreverent fellow who could not be bothered with kings and princes, but liked to debate (and to make fun of others including Confucius). The Daoists have been characterised as "irresponsible hermits" (*SSCC*1, p 85) who sought to distance themselves from conventional society and thereby to be "free".

Daoists tend to view nature with mystery and awe, with an exhortation to harmonise and even yield rather than to dominate or analyse. Indeed the intellect was frowned upon as an infringement on the free spirit. Natural phenomena are often seen in organic terms, with every part connected to every other, a "correlative" ways of thought (Hall and Ames, 1998) quite opposite to the analytic and reductionist frame of mind common in modern science. It is both strange and regrettable that resort to such manners of thought is still not uncommon in the modern Chinese mind where nature and physical science are concerned.

Daojiao as a religion is relevant because of a belief that suitable minerals (typically lead and mercury) could be baked into an elixir of immortality (*dan*); needless to say the Daoists did not have much success in their quest for eternal life, and surely there must have been cases of lead and mercury poisoning. But these early alchemists accidentally discovered gunpower, originally sought as a medicine, as well as a variety of psychedelic substances.

[6] However, one might question whether the intellectuals of the day understood science (or democracy) in our terms, and in fact the events surrounding the May Fourth protests were first and foremost about territorial sovereignty.

[7] Older texts adopting the Wade–Giles phonetic system would refer to the Tao, Taoism and Taoists rather than the Dao, Daoism and Daoists.

Buddhism

Buddhism, imported from India in phases between the first and the seventh centuries, is arguably even less relevant for science because of its interest in the *next* life rather than this one. However, Buddhism may have left positive imprints for science: the idea (even though implicit) of infinite space and time, and a focus on change rather than permanence.

Mohism

The followers of Mo Di or Mozi (Master Mo) believed in universal love, transcending familial, social and even feudal associations. Thus, they were against war, but were versed in the arts of *defensive* warfare, bordering on technology and even physical science including mechanics and optics. The practical Mohists paid attention to details, as well as mundane physical objects and phenomena — their philosophy has been characterised as a form of empiricism (*SSCC*1, p 113).

The Logicians

Of the Logicians, or *Mingjia* (the "School of Names"), who were loosely on the periphery of Daoism and Mohism, it suffices to mention only Gongsun Longzi (probably 325–250 BCE) and his famous (if apparently absurd) line "A white horse is not a horse" (*Gongsun Longzi*, "White Horse Discourse"). In modern terms, one might say that he was struggling with the notion that the set of all white horses is not the same as the set of all horses. In all honesty, Gongsun Longzi did not arrive at anything like a clear formulation, and the saying is often regarded as a riddle or even an example of sophistry.

Nevertheless Needham refers to him as representing "the highest point of ancient Chinese philosophical writing" (*SSCC*1, p 120), probably because of the unusual concern with abstract ideas.

Legalism

The Legalists, e.g., Han Fei (280?–233 BCE), espoused a strong top-down state, governed with strict and explicit codes, without the foibles of human idiosyncrasies. One can call such an arrangement rule-based, or authoritarian, or even draconian. However, the English translation "legalism" fails to do justice to the multiple meanings of the word *fa*: (administrative) methods, standards as well as law.

Qin rose to dominance among the Warring States on account of successful Legalist reforms, unifying all China[8] in 221 BCE. However, the draconian Legalist rule was certainly one cause of its collapse only 14 years later.

With such a political and social outlook, "there would be no contact between the sociology of the Legalists and the nascent sciences of nature" (*SSCC*1,

[8] As then understood.

p 275). However, could any connection be found between the laws of the Legalists and the concept of the laws of nature? Moreover, the rigid mindset and central authority promoted precision and standards. Writing was standardised; weights and measures were unified. These policies were positive for the development of technology if not science.

The Neo-Confucians

Feeling "acutely the lack of any cosmology to offset that of the Daoists, or of a metaphysics to compete with that of Buddhism" (*SSCC*1, p 227), the Song Neo-Confucians tried to "[rescue] the ethical teachings of the classics from threatened oblivion by bringing it into close contact with a reasoned theory of the universe" (*SSCC*1, p 227).

The most prominent of these scholars was Zhu Xi (1130–1200). (1) His annotation of the *Four Books* of Confucian canon[9] defined, for the next eight hundred years, the curriculum for aspiring scholars. The enforced adherence to one system of ethics and philosophy was surely an impediment for the emergence of science. (2) Chapter 2 in *Daxue* (*The Great Learning*) exhorts the scholar-gentleman who aspires to do well for the family, the state and all under heaven to start by "investigating things" (*gewu*)[10] as the path to knowledge and to sincerity of heart — apparently putting empirical observation at the foundation of human endeavours, the very essence of the scientific spirit.[11] (3) He conceived of the world as being made up of *li*, a kind of cosmic principle or rationality, and *qi*, a kind of cosmic energy. The former had precedence, so his school of thought is known as *lixue* (the study of *li*). These ideas had obvious Daoist flavours, and it is no surprise that Needham was enthused about the contribution of *lixue* to scientific thinking — a sentiment not widely shared.

The Idealists

Building upon Zhu Xi but in a serious way challenging an important aspect of his world view were the advocates of *xinxue* (the study of the heart or mind). The representative figure, Wang Yangming (1472–1529), came nearly three centuries after Zhu Xi. While Zhu Xi distinguished between *li* and *qi*, for him both resided in the external world. Wang however believed in the primacy of the mind or heart (*xin*); he and his followers would be called the Chinese Idealists. Ronan and Needham wrote that "[i]n many senses, then, he anticipated by two hundred years the philosophy of Bishop Berkeley" (*SSCC*1, p 251).

While one can argue that the sense of right and wrong comes from the heart, as innate "knowledge of good" (*liangzhi*), carrying such an attitude over to the

[9] *Daxue* (*The Great Learning*), *Zhongyong* (*The Doctrine of the Mean*), *Lunyu* (*The Analects*) and *Mengzi* (*The Works of Mencius*).

[10] Now part of the motto of HKU.

[11] However, it is debatable to what extent was this advice taken seriously; far more attention was paid to the latter parts of the famous saying, about self, family, the state and all under heaven.

knowledge of nature was surely not helpful — Wang Yangming can never be called an ally of empiricism, and the emphasis on the mind as the fountain of wisdom has not been helpful to the development of science.

4 Four great inventions

The Four Great Inventions of pre-modern China —– magnetism, gunpowder, paper making and printing —– are said by Bacon to have "changed the whole face and state of things throughout the world" (Bacon, 1620, *Novum Organum*, cited in *SCC*5-7, p xxx).[12]

Magnetic compass

(See *SSCC*3, Chapter 1)

Ronan and Needham regard magnetism as "the greatest Chinese contribution to physics".

Magnetised objects might have been used in divining boards from the first century. Accounts of magnetic phenomena and the use of the compass in navigation date from a thousand years later (*SSCC*3 p 2). Detailed observations and records included: the way lodestone points in a particular direction, the two polarities, that magnets do not align exactly in the north–south direction,[13] that iron can be magnetised (but not copper, nor pottery). Clever ways were invented to reveal the tiny turning tendency: resting a magnetised spoon on a smooth tablet, floating a magnetised object on water, making thin and sharp needles, suspending a magnetised needle from a thin thread of silk.

Yet the attempts to understand the phenomena — what we would now call basic science — were primitive, even pathetic. The following passage vividly exhibits this contrast.[14]

> If you think that because the lodestone can attract iron you can also make it attract pieces of pottery, you will find yourself mistaken ... The lodestone can attract iron but has no effect on copper. Such is the motion of the Dao.
>
> (*Huainanzi*, c. 139 BCE, cited in *SSCC*3, p 3)

One is struck not so much by the inadequacy of the explanation offered, but by the apparent satisfaction with which it was viewed. The same flavour of "scientific explanation" was to be found a millennium later for the two polarities:

[12] Actually Bacon did not include paper making as a separate entry.

[13] What we would now call the magnetic declination.

[14] It seems likely that the last fragment of the quoted material is wrong. I have gone through the whole of *Huainanzi* and cannot find anything corresponding to "Such is the motion of the Dao". An authoritative translation of *SSCC* into Chinese, by scholars from Jiaotong University, does not contain this fragment when this quote is presented. Possibly there are multiple versions of *Huainanzi*, not entirely surprising for a source that old; or possibly Needham and/or Ronan made a mistake. Be that as it may, the inadequacy of the explanation is beyond doubt.

"Just so, at the summer solstice the deer shed their horns, and at the winter solstice the elks do. Since the north and the south are two opposites, there must be a fundamental difference between them." (Shen Kuo, 1088, cited in *SSCC*3, p 10).

The widest use of magnets was in divination, and also geomancy (*SSCC*3, p 6). We need not apologise for the superstition of our ancestors, but our contemporaries going around with a magnetic compass[15] for this purpose are surely an embarrassment, and in counterpoint to Needham, perhaps "the greatest Chinese insult to physics".

The use of the magnetic compass in navigation was recorded from the 11th century (*SSCC*3, pp 27–). The most celebrated of the maritime explorations — though by no means the earliest — were those of Admiral Zheng He,[16] who lived almost a century before Columbus. Zheng He led a huge fleet (each ship many times larger than those of Columbus) "seven times down the southern oceans", visiting Southeast Asia, India, Arabia and once going as far as Africa. The use of the compass was clearly recorded in ship journals.

The magnetic compass became even more important in the hands of the Europeans, who combined it with ship-building skills, a seafaring spirit, and powerful financial incentives to sail the high seas, leading to the European discovery of the Americas. Ironically, Columbus was trying to reach China (and India) but was unaware that the magnetic compass that he used was a Chinese invention.

Without doubting that the compass was *used* and that it was *useful*, one might still entertain the query as to whether it was *essential*. First, Zheng He's route mostly hugged the coastline, made up of short legs not novel to local sailors. Columbus had other ways to tell direction: sunrise, sunset, the direction of the noon-day sun and of the polar stars at night. Thus one might plausibly argue the case that the magnetic compass, though important, was in a sense a supplementary instrument.[17] Moreover, if Columbus could not tell accurate directions, he would have landed elsewhere on the American coast — but since he had no particular port in mind, how would that have mattered?

Gunpowder

(See *SCC*5-7)[18]

Gunpowder arose out of "those ancient practices of religion, liturgy and public health which involved the 'smoking out' of undesirable things in general" (*SCC*5-7, p 1) going as far back as the 7th century BCE (*SCC*5-7, p 1).

[15] In this use called a *luopan*.

[16] By calling him "Admiral", the English-language literature erroneously conveys the sense of military expeditions. In Chinese, he is known as "Eunuch Zheng He", and his vessels were called "treasure ships".

[17] This perspective is supported by an episode recorded in Columbus' journals: when the compass deviated from astronomical readings, the latter were taken to be correct.

[18] As far as I can tell, *SSCC* never got as far as this part (namely Volume 5) of the original series.

The subject is referred to in Chinese as *huoyao*. The word *huo* (fire) more accurately captures the range, from slow burning to violent explosions obtained by tuning the ingredients. The word *yao* ("drug") reveals that explosives were linked to pharmaceuticals. The ingredients were listed as in herbal prescriptions, with the familiar labels of *jun* ("sovereign" or principal), *chen* ("minister" or secondary), and *zuo* ("adjutant" or supplementary) (*SCC*5-7, p 34).

The main ingredients of gunpowder were saltpetre, sulphur and charcoal: sulphur is easy to ignite, charcoal burns, and saltpetre (potassium nitrate, KNO_3) supplies oxygen for combustion. It was about 850 CE when the "systematic, if obscure, investigation of Daoist alchemists" (*SCC*5-7, p 15) seeking "elixirs of life and material immortality" (*SCC*5-7, p 7) accidentally and ironically stumbled upon this lethal combination. The proportion of ingredients eventually settled upon something like saltpetre 75, sulphur 15, charcoal 10, after impressively systematic investigation (*SCC*5-7, pp 94–108).

The story of additives, more appropriate to a witch's brew, is less flattering. The *Wujing Zongyao* (*The Consolidated Military Principles*) of about 1044 (*SCC*5-7, pp 118–119) recorded pine resin, sprinklings of hemp roots, dried lacquer, arsenic, white lead, bamboo roots, minium,[19] yellow wax, clear oil, tung oil and thick oil, even dried human faeces to generate "a disagreeable dust" (*SCC*5-7, p 125).

Many later advances, including good metallic gun barrels, were predominantly European. The role of artillery and skills in its use gradually expanded from the 13th to the 15th century; castles became difficult to defend, contributing to the decline of feudalism. When China was invaded in the 19th century, the balance of fire-power had already shifted dramatically against the inventors of gunpowder.

Guns[20] made a huge impact in European intrusions into in Central and South America, including the total devastation of Aztec society. The "conquest" of the American West, romanticised in so many cowboy-and-Indian films, was a story of European guns overwhelming native American bows and arrows. The Anglo–Zulu war (1879) was a tragic episode of spear-wielding natives decimated on their own land by English rifles.

Paper making

(See *SCC*5-1, Chapter 32)

The earliest writing probably appeared in Mesopotamia before 3000 BCE, using reed styluses on wet clay tablets which were then allowed to set. Within a few centuries, the Egyptians had developed papyrus scrolls to write on. Parchment and velum (different forms of leather) were known but expensive, and writing was by no means common.

The earliest recorded Chinese writing (about 1600–1300 BCE) evolved from pictures, and was carved on animal shells and bones, bronze vessels, stone tablets, and more conveniently on bamboo or wood slats. By about 220 BCE, the

[19] An oxide of lead found as a mineral, and used in very small quantities as a medicine.

[20] And also other factors such as a colonising mindset and superior military organisation.

ink brush had been invented, and writing was executed on bamboo (which does not absorb well) and then on silk (absorbent, but expensive). The invention of paper-making, by Cai Lun in the second century CE, made the written word much more accessible.

Paper-making technology is in its essence unchanged to the present day. The raw material (wood, bamboo, jute, rags or straw) is boiled in water to loosen the fibres, and then pounded into a paste. A plane sieve is run through the suspension to bring up a thin sheet of crisscrossed fibres, which is then dried under the sun, gently peeled off and then pressed. About this process several remarks can be made. (1) There was no fundamental science. (2) The multiple technical steps required patient trial and error. (3) Once the method was mastered, it could be passed on and replicated, leading to a cottage industry. These features are common to many technological achievements in traditional China.

Printing

(See *SCC*5, Chapter 32)

Undoubtedly printing originated from making imprints with carved seals. In China, stone carvings would be replicated by ink rubbings. It was then not a great leap to print from carved wooden blocks; this happened not later than the 7th century CE, without one single identifiable inventor. But carving was tedious, so printing was mostly limited to sacred Buddhist scripture.

Movable type was invented by Bi Sheng around 1045: a typeface (porcelain, wood or later metal)[21] was made for each character as the basic unit, and these were placed in the proper order on a rack, in lieu of a carved wood block. The advantage, though significant, was limited: there are thousands of Chinese characters, and each copy of the same typeface had to be individually carved. For this reason, wood block printing continued to be used for many centuries. The best historical account of Bi Sheng's invention can be found in *Mengxi Bitan* of 1166, itself printed with this technology.

In the West, Gutenberg, some four centuries later, is often cited as the inventor of the printing press; if the focus is on the word "press", then the attribution is not unjustified, for Gutenberg's system contained a number of significant advances over Bi Sheng's original invention. (1) The first advance was the use of metallic movable type. The earliest identifiable example is from Korea, in the 13th century, and the same technology was also found in China. The better durability is offset by the greater difficulty in carving, so adoption was limited. (2) The critical advance was to make multiple copies of a typeface by pouring from molten metal, in other words, *casting* rather than *carving* typeface. This was apparently known in China before Gutenberg, though not widely used and not even much emphasised.[22] (3) Gutenberg integrated the

[21] Bi Sheng carved on clay, which was then baked into porcelain.

[22] Pan (2002, pp 188–207), in an exhaustive examination of the Four Great Inventions, asserted that the metal typefaces were cast, because carving would surely have been too laborious. There are several reasons why he had to resort to such an indirect argument. First,

printing process, especially with a mechanical press probably inspired by the wine and olive presses of Europe. (4) Improvements in metallurgy had led to alloys (especially those containing lead) that had a lower melting point and could therefore be more easily handled.[23] (5) Other refinements included ink that flowed more smoothly.

These improvements, together with the advantage enjoyed by alphabetical languages in reducing the number of distinct typefaces required, led to a rapid spread of printing using cast movable type in Europe, on a scale not seen in China for many centuries.

5 Other early inventions

(This Section is based closely on "Science and China's Influence on the World", Chapter 2 of *The Grand Titration: Science and Society in East and West*, by Needham (1969). Another useful source is *The Genius of China: 3,000 Years of Science, Discovery, and Invention* by Temple (1989).)

Needham documents a long list of "the more workaday techniques which Chinese ingenuity contributed to the rest of the world".

Stirrup and horse harness

Stirrups appeared in China around the 5th century, in Europe in the early 8th century. The soldier, sitting firmly on the horse, could lance with the force of the beast. The charging cavalryman became the icon of European feudalism.

The breast-strap harness appeared in China probably in the Qin Dynasty (3rd century BCE) and in Europe some 700 years later. By enabling the horse to pull from the breast rather than through a neck collar, this "trivial" invention significantly increased the power delivered. In medieval Europe it propelled an improvement in ploughing[24] and agricultural productivity, and also allowed longer-range transport, leading to the growth of villages and then towns.

Wheelbarrow

Surprisingly, the wheelbarrow appeared in Europe only in the 13th century, at least a thousand years after its recorded use in China. Historical Chinese wheelbarrows, with the single wheel in the middle, were less tiring for long journeys — and were sometimes ingeniously aided by sails. This constituted a clever if "low tech" invention, but Needham went overboard in citing the sail as the forerunner of the aeroplane.

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metallic movable type was hardly used for books, but mostly for the serial numbers in printing paper money, so extant evidence was scarce. Second, historical accounts were often careless in using the word *ke* (carved) when they probably meant *zhu* (cast), showing at the very least that the distinction was not well appreciated.

[23] Gutenberg, before he gained fame as a printer, was a goldsmith.

[24] In China, the ox was the dominant plough animal.

Rotary gadgets, water power, bellows and belt drives

Rotary mills and their propulsion by flowing water appeared early both in China and in Europe, probably in the first century. From the Han Dynasty mills were turned through a crank (or a handle attached off-centre), or, in reverse, a wheel turned by a flowing stream could through its crank push or pull on a pane, to winnow grain or to blow into a furnace — conversion between linear and rotational motion had been invented. However, it is an exaggeration to say (as Needham did) that this formed the prototype of the steam engine and the internal combustion engine.

The moving piston of a bellows forces air out through a valve, for example onto a fire. The Chinese had double-acting bellows — which blew out in both strokes (push or pull), doubling the flow of air. The mundane invention allowed furnaces to reach high temperatures for the metallurgical industry.

There was also early evidence (e.g., *Nong Shu* of the early 14th century) of system integration: water power turning a wheel, a belt drive to transfer the motion, an off-centre crank to convert it into linear motion, pushing a piston to force air into a furnace,[25] which is used to make cast iron (see below).

The belt drive, found first in spinning wheels, was probably first invented either in India or in China. Needham argues that driving-belts found in Europe several centuries later came from Asian sources. Much larger belt drives were used to turn clockwork in astronomical observatories; a famous one by Su Song (11th century) has been rebuilt in replica in Kaifeng.

Iron and steel

When iron ore is heated in a charcoal furnace, carbon monoxide (CO) "eats away" the oxygen in the iron oxide, leaving iron as a metal. A *tiny* amount of carbon ends up in the iron, creating wrought iron — which is malleable and can be worked[26] into ploughs, swords, etc. But since gaseous carbon monoxide is dilute, the process is slow, and wrought iron could not be easily produced in large quantities.

If iron ore is mixed with burning charcoal and melted, then the charcoal, essentially solid carbon, would "eat away" the oxygen in the ore much more efficiently than would carbon monoxide, and iron is produced in large quantities, first in molten form, then poured or "cast" into moulds — hence the name. Cast iron was known in China from about the 4th century BCE, more than a thousand years before Europe.

There were however two difficulties. First, one needs temperatures high enough to melt the ore, and here the double-action bellows came into play.[27] Secondly, since there is plenty of carbon around, "too much" seeps into the iron, which ends up as brittle rather than malleable. To cure the second problem,

[25] However, in this case there was no use of the *double*-acting bellows.

[26] Indeed the word "wrought" is just an archaic version of the past participle "worked".

[27] It also helped, by a happy coincidence, that some of the iron ore found in China had a lower melting point.

the molten iron output was stirred in air, allowing oxygen to remove some of the unwanted carbon, producing wrought iron with its nice properties — but now in bulk quantities. The second improvement was known certainly in the 14th century. A segmental stone bridge in Anji, Zhaozhou was reinforced with wrought iron clasps about 1,500 years ago, and survives to this day.

The ancient Chinese inventors had no knowledge of carbon or oxygen.[28] So they could not have the conceptual framework to think about the process in the way outlined above. They developed the technology by trial and error, sometimes by accident. On the one hand, the achievements were admirable for the tenacity and industry of the practitioners; on the other hand major leaps — namely modern metallurgy — would require basic understanding and a theoretical framework.

Nautical inventions

Western ships evolved from canoes, dug from logs. Chinese junks with a more rectangular shape were inspired by bamboo and rafts. Bamboo suggested the segmentation of the hull into watertight compartments, a simple invention unknown to Europeans until well into the Industrial Revolution.

The box-like and elevated stern in Chinese ships allowed a rudder connected at its middle to a vertical shaft, thereby making it balanced and easy to turn. Of all these one can take pride, but Needham showed his Sinophile bias by suggesting that aeroplane wings were inspired by Chinese rudders.

Paddle-wheel boats powered by treadmill were known from the 5th and 6th centuries, but were used mostly in inland waters. One example, with as many as 23 paddles, was recorded about 1130. Of course, the Industrial Revolution in the West would harness steam engines to the paddles.

Discussion

All these inventions were the results of careful observation and experimentation, an area in which medieval Chinese society was proficient, putting China ahead of Europe in many domains of technology invention and use.

On the other hand one is reminded of the statement by Feng Youlan, quoted by Mote (1972) and referred to earlier: "[t]he soil-bound agricultural life [in China] was concerned with real values rather than with abstract concepts". The history of the early inventions exhibits little attention to abstract concepts or curiosity as to "why"; where such questions were posed, the enquiry was stopped in its tracks by nebulous "explanations" of the type "such is the motion of the Dao". The mainstream intellectual standard in Europe — until the Scientific Revolution — could well be summarised by a parallel sentiment: "such is the word of God", a point of view that Copernicus and Galileo were painfully aware of.

[28] Oxygen would be discovered and the nature of combustion elucidated only in the 18th century, by Lavoisier and Priestley — a watershed sometimes said to be the birth of modern chemistry.

Every CUHK student would have confronted the question:[29] How did the Scientific Revolution manage to break through those barriers? For us in this course, and as we survey the present and look to the future, can we detect a lingering neglect of abstract and fundamental questions that may impede the next stage of growth in science and technology in China?

6 Mathematics

From practical inventions we turn to more abstract domains apparently remote from direct applications, starting with selected achievements in mathematics.

Sources

The brief account by Mastin (2010) is a good starting point. A review by Needham (1954) in Chapter 19 of *SCC* considers mathematics together with the rest of science and technology. A more comprehensive account is Martzloff (1997). Chinese sources include Qian (1964) and Fu (1982).[30] Compilations such as Li and Qian (1998) are probably too detailed for our purpose.

Algebra

Traditional Chinese mathematics excelled in algebra.

A hundred fowls

Zhang Qiujian (5th century) in his *Suanjing* (*Principles of Mathematics*), posed the so-called Hundred Fowls Problem.[31]

> Each rooster costs 5 dollars, each hen 3 dollars, and chicks are 3 for a dollar. Now 100 birds were bought for 100 dollars. How many of each were bought?

In modern terms, there are 2 equations (add up to 100 birds and add up to 100 dollars) for 3 unknowns — but with solution restricted to integers. Zhang gave three solutions, with the numbers of roosters, hens and chicks being $(4, 18, 78), (8, 11, 81), (12, 4, 84)$.

The solution was not explained, and some Chinese mathematicians even a millennium later were still perplexed (Fu, 1982, p 84). No algorithm (let alone a proof) was recorded because of the premium placed on solving such problems mentally (Zhen Luan, cited in Fu, 1982, p 84). One suspects that Zhang and later mathematicians did not really understand the general case, or else they would have bragged about a problem with larger numbers.

[29] Through the required course *In Dialogue with Nature*.
[30] Occasional lapses in the latter reveal gaps in the author's mathematics.
[31] The monetary unit has been converted to dollars.

Counting soldiers

The next problem, known to the Chinese-speaking world as Han Xin Counting Soldiers, can be found in *Sunzi Suanjing* (*Sunzi's Principle of Mathematics*) of the 5th century CE.[32] The problem goes like this (Fu, 1982, p 61).

> There are an unknown number of soldiers. If you count them in rows of 3, there is a remainder of 2. If you count them in rows of 5, there is a remainder of 3. If you count them in rows of 7, there is a remainder of 2. How many soldiers are there?

The answer given by Sunzi was 23, a correct (and the smallest) solution. He certainly knew how to break the problem into three sub-problems, each with only a single non-zero remainder, for which credit is due. But he did not say how each sub-problem was solved — perhaps by trial-and-error, which is after all not difficult with such small numbers.

This problem is now taught as the Chinese Remainder Theorem. However, the *theorem*, rather than the solution for this example, was unknown to ancient and medieval Chinese mathematicians — namely the condition that the divisors (e.g., 3, 5, 7) have to be prime.

The same treatise by Sunzi contains the following peculiar problem (*Sunzi Suanjing*, cited in Martzloff, 1997, p 138): "A woman aged 29 has been nine months pregnant. What is the sex of her future baby? Answer: male." This sorry example shows that despite significant achievements, the sense of what constitutes a valid argument (let alone a formal proof) was very weak.

Square roots

How would you evaluate $\sqrt{2}$ without a calculator? First, $\sqrt{2} = \sqrt{200}/10$. Second, note that $196 = 14^2$ is the largest perfect square below 200, so let us write $\sqrt{200} = 14 + d$; then upon squaring

$$\begin{aligned} 200 &= (14+d)^2 = 196 + 28d + d^2 \\ 4 &= 28d + d^2 \end{aligned}$$

The insight is that d^2 is very small; neglecting it then gives $d \approx 4/28 \approx 0.1429$, $\sqrt{2} = (14+d)/10 \approx 1.41429$, remarkably correct to 5 digits. In general, the prescription is that if a is slightly more than a perfect square q^2 with a remainder r, i.e., $a = q^2 + r$, then $\sqrt{a} \approx q + r/(2q)$.

Liu Hui in the third century laid out this method,[33] giving in fact a lower bound; he also gave an upper bound. But he did not give any proof — not so much that he did not have a proof, but rather, the very idea of a proof was absent, though the extant literature from those days, including some diagrams (**Figure 1**), makes the line of thinking abundantly clear.

[32] This Sunzi should not be confused with the author of *The Art of War* a thousand years earlier.

[33] This algorithm was also known independently in several other civilisations.

Polynomials

There was "brilliant work [on polynomials] ... done by several contemporaries in a period covering almost exactly the last half of the +13th century" (Needham, 1959, p 40).

For example, Yang Hui (1238–1298) posed a problem which is, in modern notation,

$$5x^4 - 52x^3 - 128x^2 + 4096 \quad = \quad 0$$

He found the answer $x = 4$ (Qian, 1964, p 156) by dividing the given polynomial by $x - 4$, showing that there is no remainder. He deserves credit for developing synthetic division, but how did he know to divide by $x - 4$ and not say $x - 3$ or $x - 5$? He might have done the problem "backwards", starting with $x = 4$ and constructing the polynomial.

Li Ye (1192–1279) likewise posed and solved a problem (Hong, 1985, pp 52–54, p 127) equivalent to a 4th-order polynomial equation:

$$x^4 - 8640x^2 - 652320x - 4665600 \quad = \quad 0$$

This problem was again no doubt created "backwards".

We use this example to illustrate the method developed. (1) The polynomial is negative for $x = 0$ and positive for very large x, so there must be at least one positive root. (2) This root must be less than 1000: If $x \geq 1000$, the first term is already 10^8, overwhelming all the negative terms. (3) Thus try $x = 100, 200, 300, \ldots$. It is found that there is a change in sign and hence a root between 100 and 200. (4) Define $x = 100 + y$ and cast the polynomial in x into a polynomial in y, of the same order:[34]

$$y^4 + 400y^3 + 51360y^2 + 1619680y - 56297800 \quad = \quad 0$$

(5) The equation is still 4th-order, but instead of looking for a 3-digit number x, we now only have to look for a 2-digit number y. The process can be repeated, until we get to a single digit and another series of trials for $0, 1, 2, \ldots$ yields the answer. Even though there is trial and error, the number of steps is proportional not to the unknown x but to the number of its digit.[35]

The Chinese mathematicians went further, but there were also limitations. (1) What happens if the root is not an integer? In each step, the upper bound on the unknown is reduced by a factor of 10. Soon, the unknown is small, say < 0.01. Then the high-order terms y^2, y^3 and y^4 can be neglected, leaving a *linear* equation, which is readily solved.[36] This final step is tantalisingly close to Newton's method for solving algebraic equations. (2) The method works for polynomials of *any* order. (3) On the flip side, if one focuses on quadratic equa-

[34] Any high school student should know how to do this.

[35] In modern terms, the computational effort goes as $\log x$ rather than x.

[36] Qin Jiushao (1202–1261) had nearly but not exactly the right idea. For the unknown $y \ll 1$, one should set $y^n \approx 0$ for $n > 1$; instead he set $y^n \approx y$.

tions, one can find an explicit solution expressed in radicals — already known to early Babylonians and Indians, but not to the Chinese mathematicians. That led later to the theory of equations, with explicit (if complicated) formulas for cubics and quartics — and then to the remarkable proof by Galois in the 19th century that the general polynomial of order 5 or higher cannot be solved in terms of radicals. (4) This method can be applied to finding square (and higher) roots; computing $\sqrt{2}$ is the same as solving $x^2 - 2 = 0$. (5) The focus was on finding *one* root (usually a positive one), without regard to the others, whereas viewing all roots together turns out to be important. For example, the product of all four roots is just the final constant term, and the sum of all four roots is the negative of the x^3 term, namely zero in this case. (6) There was little awareness of a polynomial as a function or a graph. The computation was phrased in terms of the coefficients, represented by counting rods to be manipulated.

In short, Chinese algebra (indeed also geometry) was more algorithm than mathematics, with little attention to underlying and unifying theory. If some of these comments seem uncharitable, Yang Hui himself said at the time:

> The men of old changed the name of their methods from problem to problem, so that as no specific explanation was given, there is no way of telling their theoretical origin or basis.
>
> (Yang Hui, cited in Needham, 1954, p 104)

Yang Hui's triangle

The method above involves expanding a term such as $x^4 = (100 + y)^4$. More generally, the problem is to write $(h + y)^n$ in powers of y.

$$\begin{aligned}
(h+y)^0 &= 1 \\
(h+y)^1 &= 1h + 1y \\
(h+y)^2 &= 1h^2 + 2hy + 1y^2 \\
(h+y)^3 &= 1h^3 + 3h^2y + 3hy^2 + 1y^3
\end{aligned}$$

etc. The coefficients are shown in Table 1. The more symmetric version in **Figure 2** makes it obvious how new rows are generated. Yang Hui discovered this in the 13th century; in Europe, the pattern of the coefficients was discovered by Pascal in the 17th century.

1				
1	1			
1	2	1		
1	3	3	1	
1	4	6	4	1

Table 1: Yang Hui's triangle

Geometry

Characteristics of geometry

Geometry (in any culture) grew from surveying land and estimating the sizes of physical objects. The Greeks made two unique contributions: (1) the elevation of physical objects to an idealised Platonic world, involving abstract notions such as points without dimension and lines without thickness, and (2) an axiomatic framework based on rigorous Aristotelian logic. Needham (1959) thus singled out Greek geometry in relation to all others:

> It is often said that all early geometry, other than that of the Greeks, was intuitive in nature, not demonstrative, i.e. that it sought facts relating to mensuration without attempting to prove any geometrical theorems by deductive reasoning.
>
> (Needham, 1954, p 91)

Gou-gu-xian

The theorem about right-angle triangles, now invariably cited in the name of Pythagoras (6th century BCE), was independently known in many civilisations. In China, the result, under the name of *gou-gu-xian*,[37] can be found in the oldest known Chinese mathematical tract, the *Zhoubi Suanjing*, probably of the Han Dynasty (c. 3rd century BCE).

In modern notation this theorem goes as follows: For a triangle ABC with $\angle C = 90^{\circ}$, the three sides, namely base ($BC = a$), height ($AC = b$) and hypotenuse ($AB = c$) satisfy $a^2 + b^2 = c^2$. There are surprisingly many ways to prove the theorem. (1) Start with two squares with areas a^2 and b^2, and then cut-and-paste to form a square of area c^2. Several variations upon this theme are all somewhat messy. (2) Construct a square of side $a+b$ and dissect it into 4 copies of the triangle, leaving a square of side c in the middle (**Figure 3**); thus $(a+b)^2 = 4(ab/2) + c^2$. (3) Construct a square of side c and dissect it into 4 copies of the triangle, leaving a square of side $a-b$ in the middle[38] (**Figure 4**); thus $c^2 = 4(ab/2) + (a-b)^2$. (4) Use only one copy of the triangle and drop a perpendicular from C to the opposite side (**Figure 5**), cutting the original triangle into two subsidiary ones; the three triangles are similar, so the areas are proportional to the respective hypotenuses.

The last elegant method (Bhaskara's Second Proof (Head, 2018)) was given by Euclid in Book VI of his *Elements* (Britannica, 2018), but was unknown in China until the 19th century (Li and Qian, 1998, Vol 6, p 67, Figure 13).

Circumference of a circle

Every early civilisation tried to estimate π, the circumference-to-diameter ratio of a circle. Take a circle of radius 1 and inscribe a regular hexagon (**Figure 6**),

[37] The three words respectively mean the the short side (base), the leg (height) and the string (hypotenuse).

[38] Assuming $a > b$

whose perimeter, namely 6, gives a (lower) estimate for 2π — a result known to many primitive civilisations.

Next double the number of sides. Then repeated use of Pythagoras' theorem yields the perimeter of the new polygon, giving a better approximation to 2π. This procedure is repeated, with polygons of 6, 12, 24, 48, ... sides. Liu Hui (3rd century) used 96 sides to get π to 5 digits, but remarkably Zu Chongzhi (429–500) showed $3.1415926 < \pi < 3.1415927$, with error in the 9th digit — an accomplishment unequalled for many centuries. He must have used nearly 30 000 sides. The task was enormous; even taking a square root was tedious. Most Chinese accounts tend to be effusive about Zu's work. But he merely pushed to polygons of more sides a method already known to Liu Hui and indeed Pythagoras (MathWithoutBorders, 2012), so he should be admired more for industry than for originality.

Geometry of the heavens?

Traditional Chinese mathematicians applied their geometry almost exclusively to problems terrestrial rather than celestial, revealing their practical inclination. In contrast, the Greeks and the Egyptians were much concerned with the paths of heavenly bodies. Descriptions in terms of circles quickly progressed to circles upon circles. Though now often belittled in comparison to Copernicus and Newton, the Ptolemaic astronomers should instead be lauded for their concern with accuracy and not just approximate descriptions.

Neither emphasis on accuracy in explaining natural phenomena nor mathematical interest in the heavenly bodies occupied ancient Chinese thinkers. There was the vague notion of a celestial sphere; the well-known saying "*tian yuan di fang*" ("the heaven is round and the earth is flat")[39] can be found in *Zhoubi Suanjing*. However, this vague statement led to few quantitative investigations.

Conic sections

The next level of sophistication in plane geometry would be conic sections: ellipses, parabolas and hyperbolas. These were known to the ancient Greeks (Lahanas, n.d.). Conic sections had no immediate utility, and the algebraically inclined Chinese mathematicians would not have affinity for the intrinsically geometric point of view of a plane cutting a cone.

Imagine what delight would have greeted Kepler's discovery that planets move in ellipses and Newton's realisation that such orbits follow from an inverse-square force — conic sections were in the realm of the divine! The status thus accorded to mathematics and mathematicians should not be under-estimated, and there was no parallel in China.

[39] My translation. However, "round" may have meant something like a circular disc rather than a sphere.

No calculus

Calculus never developed in China, but was only imported in the period of convergence. Like the dog that did not bark in the night (Doyle, 1892), this clue has been largely overlooked by the mainstream literature.

Yet calculus is without doubt the singular leap that launched modern mathematics, and its mastery at some level can with little exaggeration be regarded as the standard that defines mathematical literacy in the 21st century. So the failure of Chinese culture in this respect is a significant historical fact that invites reflection, as one strand of the broader question that occupied Needham: Why did modern science fail to develop in China (Sivin, 2017)?

No mathematisation of science

Mathematics in the Western tradition was not just an academic subject in its own right, but the pedestal upon which stands the whole edifice of science. One is reminded of the famous saying:

> Philosophy is written in this grand book — I mean the universe — which stands continually open to our gaze, but it cannot be understood unless one first learns to comprehend the language in which it is written. It is written in the language of mathematics, ...
>
> (Galileo, 1623, translated in Popkin, 1966, p 65)

Newton (1687) encapsulated the very idea of the mathematisation of science in the title of his treatise: *Philosophiae Naturalis Principia Mathematica*.

There was nothing similar in traditional Chinese mathematics, a contrast noted by Needham (1969, p 16). It surely was one of the reasons why a Scientific Revolution did not occur in China, and consequently why China was technologically and militarily weak in its encounters with Western powers starting from the mid-19th century. It may be an exaggeration, but not a falsehood, to say that mathematics is a major element that has influenced the course of modern Chinese history.[40]

7 Astronomy

(I am indebted to Dr KM Pang for much of the material in this section.)

The same night sky[41] is available to every civilisation, and the sense of mystery and curiosity must also be universal, not to mention the importance of the seasons for agriculture. Thus the historical development of astronomy invites comparative study. The account below is in many places only approximate, but hopes to capture the important features.

[40] In the sense of "for want of a nail ... the kingdom was lost".

[41] Apart from small differences depending on latitude.

Purpose and organisation

While one tends to think of astronomy nowadays as the science of the solar system, the galaxies and the cosmos, in ancient and even medieval China, its primary significance was associated with rituals and the imperial court. The emperors derived their legitimacy from a "mandate of heaven", and astronomical phenomena were manifestations of this mandate. Astronomical observations were carried out by court-appointed officials — and by no others, on pain of severe punishment; astronomical data and methods were state secrets. Compilation of the calendar was an essential part of the practice of astronomy, and likewise a closely guarded court function.

In the hands of the court, very good records were preserved. However, the absence of private astronomers was unfavourable for innovations.[42]

Observations

As with all ancient civilisations, astronomical objects were located by groups of stars (constellation or asterism)[43] nearby, which serve to define a direction on the celestial sphere. For example, the seven brightest stars of the *Ursa Major* constellation are collectively called Beidou by Chinese astronomers. Astronomical objects and occurrences were categorised according to the degree of regularity: (1) the constellations (or in Western tradition the celestial sphere on which they are embedded) that rotate once a day — of course, in modern terms, that is only the rotation of the Earth about its own axis; (2) the motion of the Sun and the planets relative to this background, on time scales of years, and also the Moon with a cycle of about a month; (3) rare events such as eclipses and conjunctions, i.e., several heavenly objects lining up in a row[44] — irregular but actually predictable, with the ability to do so a measure of astronomical prowess; and (4) extremely rare and unpredictable events such as meteors, comets[45] and supernovas.

Ancient Chinese astronomers were proficient in observing and recording. An interesting example was the extremely bright object in the Tianguan constellation (*Zeta Tauri*) observed in 1054 (in modern terms a supernova, SN1054) — so bright as to be visible in daytime for nearly a month. Chinese astronomers also had considerable success in predicting eclipses. However, the Jesuit missionaries in the late Ming produced better predictions, for two reasons: (1) they had a

[42] In this regard, perhaps the European scheme of royal patronage was the best of both worlds: the court supported astronomical investigations but did not tightly control it. It might be recalled that Newton's breakthroughs relied heavily on Kepler's empirical laws, formulated on the basis of accurate observations by Tycho Brahe, who was supported in turn by King Frederick II of Denmark and the Holy Roman Emperor Rudolph II.

[43] In modern understanding, such stars are in nearly the same direction as viewed from our position, but could be at very different distances — thus they do not in general form a cluster at all.

[44] These are "special" only when seen from our particular position, and have no intrinsic significance.

[45] As a triumph of Newtonian mechanics, comets have become predictable, the most famous being that of Halley.

geometric model (indeed a heliocentric one)[46] whereas the Chinese astronomers relied on algebraic interpolation and extrapolation; and (2) the Chinese astronomers had failed to update their parameters since the Yuan Dynasty. This would turn out to be an early and dramatic demonstrations (directly to the imperial court) that Chinese astronomy, despite the mass of observations and rich compilation of data, was actually falling behind Europe.

Calendar

The traditional Chinese calendar makes reference to *both* the lunar cycle and the solar cycle, hence the name *lunisolar*; the common name "lunar calendar" is a loose shorthand. The lunar month is pegged to the lunar cycle of 29.53056 days, say from new moon to new moon, producing something like a monthly calendar-in-the-sky for even illiterate farmers. In fact, the traditional calendar is also called *nongli* or agrarian calendar.[47]

The convenience comes at a cost: it is much more difficult (say for the court astronomer) to *construct* the calendar — or for us to understand that construction. The complication lies in three ratios: 365.24219 days to a year, 29.53056 days to a lunar cycle and 12.36828 lunar cycles to a year[48] — and the fact that they are not integers. Thus, the fractional part of 365.24219 (about 1/4) leads to the need to insert an extra day every four year.[49] There are two other problems: how to fit 29 or 30 days into a lunar month, and how to fit 12 or 13 lunar months into one year — the latter connected with the most important event for Chinese communities, the Chinese New Year.

Fitting days into lunar months

Each lunar month begins when the new Moon appears (which may happen any time from 00:00 to 11:59 of that day). The next lunar month begins with the next new Moon — which can be either 29 or 30 days later. Thus there are "long months" and "short months", occurring without a simple pattern.[50]

Fitting lunar months into years

Chinese New Year occurred on 5 Feb 2019, with new Moon at 05:04 Hong Kong time, i.e., new Moon occurred at Day 36.210.[51] Going forward 12 lunar cycles takes us to the following Day: $36.210+(12\times29.53056) = 390.576 = 365+25.576$.

[46] However, the Jesuits would not overtly use the heliocentric language.

[47] Up to about one century ago, most Chinese would exclusively use *nongli* in celebrating birthdays.

[48] The last number is the ratio of the previous two.

[49] The actual rules are more complicated because the fractional part is not exactly 1/4; see for example Chan, Pang and Young (2022).

[50] Roughly speaking, if new Moon occurs at an early hour, the month is going be a "short month".

[51] 5 Feb is Day 36 (31 days in January + 5), and 5 h 4 m is 0.210 days.

So Chinese New Year 2020 occurred on Day 25, i.e., 25 Jan 2020. Thus Chinese New Year typically occurs 11 days earlier every year.[52]

But Chinese New Year cannot get earlier steadily — all the way to summer. A window is prescribed: Chinese New Year is restricted to the period 21 January to 19 February. If the calculated date falls before this window, an extra or intercalary month is added. There is another set of rules to determine where the extra month is inserted.

Solar terms

The lunisolar calendar does not synchronise with the seasons, and would not be adequate for agricultural practice. The solution is to completely forget the lunar motion and just look at the solar cycle, and divide the 365.24219 days into 24 *solar terms* or *jieqi*, sort of like half-months of a solar year. Not much is gained by a casual student of the subject in trying to learn the names; let us just call them $T1$ to $T24$,[53] starting with spring equinox as $T1$, and each occupying about 15 days. Thus the court astronomer would be tasked to calculate and then insert the solar terms into the lunisolar calendar, which is then promulgated.[54]

Coordinates

To specify direction in the sky and locate an astronomical object, this is what we need to do. First choose a plane and imagine marking on it 360° like a compass dial, with 0° along some conventional direction. Take a sighting tube and lay it on the plane, in direction φ. Then lift the sighting tube an angle α above the plane. The two angles (φ, α) are then the astronomical coordinates of the object.

However, what plane do we start with? Three choices are illustrated in **Figure 7**. (1) One can choose a *horizontal* system, but then the reference plane would not be the same for observers at different locations, hardly convenient if astronomy is to be practised globally or even across a moderately large region. (2) One can choose the *ecliptic* system, making reference to the orbital plane of the Earth.[55] This was natural for Europeans who had inherited the tradition from tropical (e.g., Egyptian) astronomers who obviously placed importance on the Sun, and given the interest in the intricacies of planetary motion. (3) One can choose an *equatorial* system, making reference to the equatorial plane, or equivalently a plane parallel to the arcs traced out nightly by the stars on account of the rotation of the celestial sphere — which is how pre-Copernican astronomers would have described the effects of rotation of the Earth. Chinese

[52] There could be rounding changes due to the hours, and due to any Gregorian leap year.

[53] However, the names of at least some of the terms have definite agricultural connotations, such as *yushui* (spring showers), *guyu* (wheat rain), *mangzhong* (seeding millet).

[54] Incidentally, the interval between sucessive winter solstices is called *sui*, whereas the interval between successive Chinese New Years is called *nian*.

[55] Before Copernicus, one would say instead the plane defined by the apparent motion of the Sun. This plane is called the ecliptic because an eclipse can only occur when the Moon crosses this plane.

astronomers had used the equatorial system from antiquity, probably because (living at higher latitudes) they were more captivated by the polar stars, around which all the other stars seemed to revolve, like subjects around a king.[56] The direction of the polar stars is, of course, just the perpendicular to the equatorial plane.

The equatorial system was adopted in Europe only in the 16th century, and is the standard today. In this case, the angle φ measured *relative* to the direction to the Sun at spring equinox is called the Right Ascension, RA, while α is called the Declination. The advantage of the equatorial system is that as the Earth rotates, φ measured *relative* to a fixed point on the celestial sphere remains unchanged, and α is also unchanged. In essence, one has removed the rotation of the Earth and gone to a system affixed to the celestial sphere.

Instruments

The description of the coordinate systems involving two angles naturally leads to the idea of armillary spheres for pointing a sighting tube. The first or base ring allows rotation on the plane. A second ring situated in a perpendicular direction controls the elevation. Such an instrument, designed on the basis of equatorial system, is shown in **Figure 8**; the base ring is tilted from the horizontal (by an angle equal to 90^o minus the latitude). The overwhelming advantage is this: to track a fixed star, one *only* has to rotate the base ring at the *constant* rate of 15 degrees per hour, leaving the second ring fixed. More advanced versions would use clock drives to rotate the base ring, and a replica of such a huge instrument from the Song Dynasty has been recreated in Kaifeng.

Amazingly ancient Chinese astronomers arrived at this scheme while being ignorant about the Earth as a rotating sphere and about the equator.

Astronomy was taken to a totally new level with the uniquely European invention of the telescope, a serendipitous collision between the glass-making craftsmanship of Venice (which survives to this day) and the scientific imagination of Galileo.

Cosmological models

How did the ancient Chinese conceive of the cosmos? There were three main schools of thought. (1) The *gaitian* model, cited in the Zhou Dynasty, thought of the sky as a canopy above the earth.[57] (2) The *huntian* model thought of stellar objects as lying on a spherical (or more precisely a semispherical) surface above the Earth, not unlike the crystalline sphere of Greek astronomical models. (3) The *xuanye* model thought of heaven as infinite space, in which celestial objects floated. Each model contains elements that come close to some

[56] "The Master said: He who exercises government by means of his virtue may be compared to the north polar star, which keeps its place and all the stars turn towards it." (*Lunyu* (*The Analects*), Chapter 2, "Weizheng", verse 1; translation by James Legge).

[57] The canopy was thought to be "round" in the sense of a circular disk parallel to the flat Earth.

aspects of modern thinking, and the *xuanye* model is often praised for being quite accurate about infinite space. However, with the exception of some early works (unfortunately not later pursued) based on the *gaitian* model,[58] there was little attempt to develop any scheme to a level that would allow quantitative comparison with detailed observations — not so much that the Chinese astronomers failed in that attempt, but that there was no sense that this would be a worthwhile endeavour.

In contrast, the Ptolemaic model, though now typically viewed in a negative light in comparison with the Copernican model,[59] had tried *extremely* hard (with epicycles, the eccentric and the equant) to account for every detail of observation. Those who wax lyrical about the insights of early Chinese cosmological models should be reminded that these models were "not even wrong".[60]

8 Modern ideas from the West: the missionaries

(I am indebted to Dr FC Chen for much of the material in this section.)

Interactions with the West

It must not be thought that science and technology in China had developed in isolation until the arrival of the Europeans. Interchange with neighbours occurred through trade, conquests (in both directions) as well as dedicated expeditions.[61] For example, Chinese mathematics had definitely absorbed elements of Indian and Arabic achievements. But these earlier interactions had been marginal rather than central to Chinese history, with the possible exception of Buddhist ideas being imported. In the realm of science and technology, the interchange was between civilisations at similar levels of development, without any cultural shock.

[58] For example, there were well-known attempts to determine the height of the Sun above the Earth. This was indeed detailed and quantitative, but several remarks can be made. First, the starting point was the difference in the length of a shadow (cast by a standard vertical rod) in different places. However, the results were so wrong (Cuprie, 2018) that the "data" were very likely not real measurements, but themselves speculations, or possibly taken from other civilisations and mistakenly changing the units. Second, even with correct data, such a calculation would give something like the radius of the Earth (now that we know it is round) rather than the distance to the Sun — for which the ancient Chinese astronomers cannot be faulted. But the most important reason for not giving too much credit to the *gaitian* model as a quantitative cosmology is that the same determination of the distance to the Sun can be made without assuming a "canopy".

[59] In fact, in terms of quantitative agreement with observations, the Ptolemaic scheme was no worse than the early Copernican models.

[60] This harsh criticism of some attempts at science, often grand-sounding science, is attributed to Pauli, and was probably uttered in the 1930s or 1940s about a particularly unclear paper. The phrase has gained currency in the 21st century as a criticism of string theory for not having testable predictions, and is even the title of such a book (Woit, 2006). The underlying epistemological criterion for science is famously encapsulated by the principle of falsifiability by Popper (1959).

[61] The journey of Monk Xuanzang to bring Buddhist scripture from India is one of the most celebrated.

The story from the middle of the 16th century would be different: with the Renaissance, the Scientific and later the Industrial Revolution, Europe had forged ahead. The interactions became unequal, eventually engendering cultural and military shocks, with major repercussions on modern Chinese history.

Two periods of interflow

The story of interaction with the West in science and technology went through two distinct periods: (1) starting in late Ming and early Qing with the first awareness of European advances in science; and (2) culminating in the late Qing and in the early Republican era when the full force of European might and military aggression powered by the Industrial Revolution shattered confidence and complacency, resulting in nation-wide anguish and desperate efforts to catch up. This section deals with the first of these two parts, focusing on the interchange mediated by the missionaries of this period, with special attention on Matteo Ricci and Adam Schall, if only because they are well known in Hong Kong.

Historical context

Ricci arrived in China in 1582 and Adam Schall in 1619. These dates are after Copernicus (1543 publication of *On the Revolutions of the Heavenly Spheres*), but before Galileo (1632 publication of *Dialogue Concerning Two Chief World Systems*) and of course also before Newton (1687 publication of *Principia*) and Watt (1764 invention of steam engine). Thus the modern European science that they brought was very much in its infancy, and the Industrial Revolution as well as the consequent European power was not yet on the horizon.

The Jesuit movement

The Society of Jesus is a Catholic order founded by Ignatius Loyola in 1540, in part as a response to the challenges posed to the Catholic church by the Protestant Reformation (Martin Luther having posted his *Ninety-Five Theses* in 1517). Members of the Society, known as Jesuits, were typically very well educated, not just in Catholic doctrines, but also in languages and in the sciences that were then just beginning to emerge in the Renaissance. These celibate priests committed themselves to spreading the faith, especially outside Europe. The Society is even today engaged in religious, educational and charitable work across the world. Wah Yan College in Hong Kong was started by the Jesuits,[62] and the current (2021) Catholic Bishop of Hong Kong, Stephen Chow, is a member of the Society of Jesus.

[62] Wah Yan was established in 1919. Wah Yan (Kowloon), established six years later, became an independent school in 1933.

Ricci

Matteo Ricci, an Italian[63] Jesuit, arrived in Macao in 1582,[64] with the intention of converting people to the Catholic faith. He genuinely respected the local population and their culture, and settled down to learn the Chinese language including the written script (which at that time was of course classical Chinese) before moving to Zhaoqing in Guangdong, where he stayed for six years. He took on the Chinese name Li Madou. With Macao being in many senses his base, Ricci is well remembered in these parts: in Macao the Ricci Insitute, Casa Ricci Social Services, Colegio Mateus Ricci (a high school); in Hong Kong Matteo Ricci College in Kwuntong, and Ricci Hall in HKU.

His first work of note was a modern map of the world, rendered in Chinese, bringing knowledge of the New World to China, as well as explicit recognition that the Earth was round — Magellan had reached the Philippines via the Americas in 1521. He also produced a Chinese–Portuguese dictionary,

Ricci took his cultural and missionary work north, to Jiangxi, Nanjing and finally Beijing in 1598, fully 16 years after he set foot in China. In 1602, he gained access to the imperial court (though he was not received by Emperor Wanli himself), on the strength of his prowess in astronomy: he had predicted an eclipse more accurately than the court astronomers. He also brought the geometry of Euclid to China, which in some ways was more important (see below). Leveraging on royal acceptance, he was able to build a cathedral in Beijing, and converted a number of senior officials. In many ways, science was for him a tool for the purpose of religious conversion. His missionary work was helped by his acceptance of Confucianism, to the extent of adopting Confucian gowns and trying to reconcile some practices, for example allowing Chinese Catholics to worship ancestors — an issue that would erupt some years later. Ricci died in Beijing in 1610, having spent 28 years in China. Special imperial permission was granted for his burial in Beijing.

In short, he brought more advanced European mathematics, geographical knowledge and astronomy to China. The substantial influence was however mostly limited to the higher echelons of official society, with the bulk of the population, even the majority of scholars, largely unmoved and even unaware of these developments far from daily life.

Adam Schall

Johann Adam Schall von Bell was a German[65] Jesuit. His name is a bit tricky. The family name is "Schall von Bell", so he was "Mr Schall from (the place) Bell"; the "von" signifies that his family was among the nobility. Of his two

[63] Italy in the modern sense did not yet exist; Ricci was born in Genoa.

[64] There was Portuguese presence in Macao well before the British showed up in Hong Kong. Spain and Portugal were more formidable maritime nations than England, at least up to the defeat of the Spanish Armada in 1588. Columbus, like Ricci an Italian, embarked on his journey to America — not knowing about the New World and in the belief that he was seeking China and India — under Spanish royal patronage.

[65] Germany in the modern sense did not yet exist. He was born in Cologne.

given names, "Adam" is used more often. Thus, he is typically called Adam Schall. But "Johann" should not be forgotten: that is where the last two characters of his Chinese name "Tang Ruowang" come from. He should be well known in CUHK — there is the Adam Schall Residence in United College, built in 1971 with support from the Society of Jesus.

He came to China as a missionary, first landing in Macao in 1619, following Ricci's footsteps 37 years earlier. In Macao he learnt the Chinese language and customs, and then went north for his missionary work, reaching Beijing in 1630. The Jesuits, from Ricci onward, had gained a reputation in China for expertise with calendar construction. He worked with Xu Guangqi (see below), and they compiled a new calendar named after Emperor Chongzhen, whose reign would turn out to be the last in the Ming Dynasty. This calendar was judged to be superior in predicting eclipses.

He had even greater influence at the Qing court, gaining the trust of Shunzhi, the first Emperor on the throne after the Qing conquest in 1644. He became a court official, the first European ever to do so, holding appointments in the bureau of mathematics and even directing the official observatory; in these roles he wore the robes of a court official. Although the spread of Christianity is not our primary concern, it is worthwhile to note that his proselytising, building on the foundation of Jesuits before him, was very successful, with over half a million converts.

The officials displaced from the observatory were understandably unhappy, and had Adam Schall ousted and even imprisoned on various charges; he died soon after release from prison. Like Ricci, he was buried in Beijing.

Xu Guangqi

The story of Ricci and Schall would not be complete without that of their Chinese ally, Xu Guangqi.

Xu was an extraordinary scholar of the Ming Dynasty. He was of course well versed in the traditional Confucian curriculum, without which he could not have become an official; he eventually, in the reign of Chongzhen, gained an exalted rank equivalent to deputy prime minister. But unusually among Confucian scholars and court officials, he also had expertise in agriculture, mathematics and astronomy, and he was among the first Chinese converted to Catholicism. In these latter respects, his path intersected with those of Ricci and Schall, and with our account of science and technology in China.

Xu was born in Shanghai.[66] In 1600, as a mid-level scholar and not yet an official, he met Ricci in Nanjing; three years later he was baptised. In 1604, he passed the highest level in the imperial examination, and was appointed to a three-year probationary post in the Hanlin Academy. In that period his career took an unusual turn: instead of (or perhaps in addition to) doing what such a junior official would normally do, he worked with Ricci to translate the *Elements* of Euclid, completing the first six chapters, on plane geometry — the first ever

[66] At that time not yet a major city.

translation of a Western scientific text into Chinese. Although he, together with Ricci, also translated other works, the *Elements* was pivotal, since it showed mathematics at a totally different level of rigour and systematisation. Xu also collaborated with Schall to produce an improved Chinese calendar, named after Chongzhen. Among the novel features (which of course few understood) was a correction to take account of the slightly non-uniform motion of the Earth in its orbit[67] — a feature much emphasised in the West since antiquity and expressed through the eccentric and the equant of Ptolemaic astronomy; Adam Schall probably knew about Kepler's elliptic orbits and the equal-area law announced in 1609, a decade before Schall's arrival in Macao.[68]

Xu died in Beijing in 1633; his tomb is in Shanghai, in fact in the district Xujiahui, literally "the confluence of the Xu family".

So Xu was very much a Renaissance man, in two senses: he was a polymath, knowledgeable across many fields, much in the manner of say Da Vinci, and he was the first Chinese to appreciate, and to attempt to spread, knowledge that came from the European Renaissance. Some historians go so far as to call this period the birth of a Chinese Enlightenment,[69] and many scholars in the West regard the contact with the missionaries (rather than the Opium War more than two centuries later) as the watershed that marks the start of the modern era in Chinese history.

The rites controversy

The Jesuits gained their foothold in China through acceptance of traditional Chinese customs, in superficial matters such as dress and taking on Chinese names, in more fundamental ways through acceptance of a set of practices which in modern parlance might be called "Catholicism with Chinese characteristics", for example allowing worship of Confucius and of ancestors, in parallel with worship of the Christian deity. The Qing court was initially tolerant, Emperor Kangxi issuing an edict in 1692 that gave Catholicism official status similar to Daoism and Buddhism — perhaps not surprising since Buddhism was also a foreign import. But conservatives on the Catholic side complained to the Pope, who in 1705 ordered that Chinese Catholics must not worship Confucius or ancestors; this then led to retaliation from the Qing court, and in 1721 Kangxi banned foreign missionaries except in Macao. Thus ended about a century of interesting exchanges between two civilisations, with science and technology being an important strand in that process.

[67] Or equivalently the apparent motion of the Sun.

[68] However, the missionaries, being Catholics, did not dare to openly use a heliocentric language.

[69] This parallel must be regarded as stretched, since the European Enlightenment is typically dated from the 18th century.

Two-way exchange

In this period straddling late Ming and early Qing, the interchange was very much two-way, with the West also learning from China, to a large extent through the missionaries and their writings. This remark is important, for it demonstrates that China was at that time not regarded as backward. Thus Europeans gained a fondness for Chinese porcelain, furniture, decorations and art, and there was among the upper classes a "Chinese craze", known in France as *Chinoiserie*. If afternoon tea is now thought of as quintessentially English, it should be remembered that tea came from China around this period.

There was also admiration for the way Chinese society was organised, and the Confucian philosophy and ethics at its base. *The Orphan of Zhao*, a play first translated by a Jesuit in 1731, became well known in Europe. Voltaire adapted the play some two decades later, regarding it as a powerful message about morality. Indeed Voltaire argued that Europe should learn from Confucianism (which, in all honesty, he knew only superficially) as an alternative to the political system then prevalent in Europe.[70] One can hardly avoid the ironical mirror image: some of the May Fourth leaders calling for wholesale adoption of Western ideas (which they knew only superficially).

9 Modern ideas from the West: late Qing to early Republican era

(I am indebted to Prof Frederick Cheung for much of the material in this section.)

We now come to the period from the late Qing (c. 1860) to the early Republican era (c. 1920), when learning from the West, of course including science and technology, became a motif in Chinese history. Modernisation in science and technology, as in much else, came to be seen with urgency and desperation as a necessity for the survival of the nation[71] and the people — a tone entirely different from the gentle interactions mediated by the missionaries and the mild responses thereto. Three themes will be examined: the Self-Strengthening Movement in the late Qing, the May Fourth Movement in the early Republican era, and study abroad.

Self-Strengthening Movement

Context

The Self-Strengthening Movement (1861–1895), also called *yangwu yundong*,[72] can only be understood in the context of the national descent into crisis and despair in the late Qing, some 120 years after the glorious reign of Kangxi.

[70] Remember that this was the period before the French Revolution.
[71] The modern concept of a nation was itself developed only in this period.
[72] Foreign Affairs Movement.

The First Opium War (1839–42) saw humiliating Qing defeat at the hands of a relative small British force. By the resultant Treaty of Nanking,[73] "reparation" was to be paid, ports were to be opened, and importantly Hong Kong Island was ceded. Although battles were fought across China, on land and on sea, the enduring image is the naval battle where a Chinese fleet of wooden junks propelled by wind faced a much smaller British fleet of ironclads propelled by steam and decked with powerful cannons — the outcome was foregone. Lin Zexu, the Imperial Commissioner at the forefront of this conflict, referred to the foreigners' "sturdy ships and fierce cannons" in a submission to the Emperor, and the phrase *chuanjian paoli* has entered the vocabulary and the minds of Chinese as a shorthand for national distress caused by technological inferiority — and therefore an animating principle for modernisation and for development of science and technology.

The conflict was reignited in the Second Opium War starting in 1856, this time with the British being joined by the French, and with Russia and the US complicit. Beijing fell in 1860, the Emperor fled and the Old Summer Palace[74] was looted and burnt. The War ended in another humiliating agreement: the Convention of Peking,[75] which, among other concessions, ceded Kowloon Peninsula[76] to Great Britain.

If there could have been a pretense at court that the First Opium War was peripheral to the country and that life could go on as before, the Second Opium War struck visibly at the heart of imperial power. Something had to be done, urgently — and this was the immediate impetus for the Self-Strengthening Movement, a series of reforms that started as soon as hostilities with the British and the French ceased.

Leaders

The reforms were led by Prince Gong, who had gained authority by staying in Beijing in 1860 when his elder brother Emperor Xianfeng fled from the Anglo–French invasion;[77] he later took charge of the negotiations leading to the Convention of Peking. When Xianfeng died a year later, his son and heir Tongzhi was only six, and after a series of palace intrigues power fell to the mother of the young monarch, Empress Dowager Cixi, "ruling behind the curtains" and allied with Prince Gong as Regent. Thus there is no question that the reforms were backed by authority from the top, especially through the Zongli Yamen, a newly formed office dealing with foreign affairs, headed by Prince Gong himself.

[73] Instead of "Nanjing", we follow the original document in its English version, which refers to "a Treaty ... concluded and signed ... on board Our Ship the Cornwallis, at Nanking, ... " (Treaty of Nanking, 1842).

[74] Yuanming Yuan; not to be confused with the Summer Palace, Yihe Yuan.

[75] Instead of "Beijing", we follow the original document in its English version, which is labelled as a Convention "Signed at Peking". This treaty was also published in the Hong Kong Government Gazette in December 1860 (Government of Hong Kong, 1860).

[76] South of Boundary Street, which is the reason why the street is so named.

[77] This escape, towards the north-east, should not be confused with the better known flight of the imperial court, including Cixi and Emperor Guangxu, some 40 years later when the capital was again threatened, in the latter case towards the west.

Actual work was led by a number of senior Han officials, of whom only three will be mentioned: Zeng Guofan, Li Hongzhang and Zhang Zhidong.[78] These leaders were all educated in the Confucian tradition, had all passed the highest level of the imperial civil service examination and had earned official appointments. But they also had their own regional power bases because of the provincial armies they led (in the case of Zeng and Li) in quashing the Taiping rebellion; thus they had a degree of autonomy in carrying out reforms that would not have been available to provincial governors in a different age. The autonomy helpfully allowed initiatives, but also caused a lack of coordination — despite the name, the Self-Strengthening Movement was not a single national Movement, but a loose collection of like-minded initiatives often at provincial level.

These champions of Western technology knew little about the West or about technology (much less about science) — in stark contrast to Xu Guangqi in the late Ming. They did not know any European language and had not been abroad.[79] They were not schooled in technology, except for the certain knowledge that cannons could be devastating. Yet, this group of senior officials were the best that could be mustered across the entire country.

Assessments of these senior officials range from praise for their valiant (even if not entirely successful) efforts in modernising the country, to criticism for putting down the Taiping Rebellion regarded as a righteous peasant uprising, and for massacres in Nanjing (Zeng), agreeing to unfavourable and humiliating treaties with foreign powers (Li), and standing in the way of progress by defending the political status quo (Zhang).

Achievements

The earliest proposal was simply to buy armament and industrial products from the West, but it was quickly realised that a better plan was to develop China's own industrial capability. The iconic development was the Jiangnan Arsenal in Shanghai, very much due to the effort of Zeng and Li, with Westerners leading the engineering staff. This facility of course produced munitions and weapons, but despite its common name in English,[80] was also very much engaged in ship building and even in translation. The shipbuilding operation was later hived off into the Jiangnan Shipyard, which survives to this day — and has been responsible for building aircraft carrier 003.[81] Similar operations were launched in several places including Tianjin, Wuhan, Nanjing, Fuzhou and Xian.

The domestically built ships were hardly adequate, and a parallel effort was

[78] Together with Zuo Zongtang, they would be known as the four great ministers of the late Qing. Zuo was a military man who importantly regained control of Xinjiang for the Qing Dynasty; his contributions to science and technology in the Self-Strengthening Movement were comparatively limited.

[79] Much later, Li Hongzhang would famously represent the Qing government in several missions abroad, and would become known in the West.

[80] The full name in Chinese referred to machinery and manufacturing, with no explicit reference to arsenal or weapons.

[81] Carrier 001 is a refurbished Russian vessel; carrier 002 was built in a shipyard in Dalian.

mounted, under the direction of Li Hongzhang, to purchase naval vessels from Europe in order to establish naval fleets. The most famous of these was the Northern Fleet based in Shandong, with impressive statistics on tonnage and firepower.

From munitions, weapons and ships, one is obviously led to the need for metal works, coal mines, as well as machinery for these enterprises. The transport requirements prompted the development of railroads, initially only short stretches, for example between Beijing and Tianjin. Telegraph was also introduced, again short lines to start with. A proposal to lay a maritime line from Shanghai to Guangdong was wisely scotched, because inland lines could be more firmly grasped in Chinese hands. Many of these enterprises were operated by private owners and investors under government supervision (*guandu minban*).[82]

Apart from building up the defence industry and more broadly the public infrastructure, the reforms seeded the growth of private-sector industries — from an extremely low base. Even the humble matchstick was first imported in this age, and was known as *yanghuo* ("foreign fire"). The earliest domestic matchstick factory was established only in 1879, in fact in Foshan not far from here (Sohu, 2021). Other industries that developed in this period on the strength of Western technology included paper-making (even though the primitive variety is touted as one of the Four Great Inventions of ancient China), cement, as well as domestic water and electricity supplies. These industries sprang up mostly in and around the treaty ports, and must be one of the roots of the current developmental gap between coastal and inland provinces. The factories were often owned and controlled by foreigners, though a group of "national industrialists" began to emerge.

Just as important, though less often remarked, is the birth of a small middle class and of a capitalist system in its infancy, including the establishment of corporations in the modern sense, based on ownership of shares. For example, the China Merchants Group (CMG), also called *Zhaoshangju*, is a Fortune-500 company (ranked 163 globally) now headquartered in Hong Kong, with about 250,000 employees and annual revenue of USD 60 billion (Fortune, 2021). The company says on its website (CMG, 2021): "[CMG] was founded in 1872 as the first commercial corporation in China, more importantly as the pioneer of national industry and commerce. It played a significant role in modern China's economic development and social development, pushing China forward in many historical moments." The establishment of the company is part of the story of the Self-Strengthening Movement, and its founder was none other than Li Hongzhang.[83] To service the growing industry and commerce, modern banks also came onto the scene during this period, initially foreign-owned and operated outside Chinese government control. One of the first was the Hongkong and Shanghai Bank[84] incorporated in Hong Kong in 1865, with a secondary office in

[82]Those who know their history would realise that a somewhat heavy government hand on key industries is not a practice invented by the current administration.

[83]CMG is today, as it was at the time of establishment, a state-owned enterprise (SOE). SOEs, for better or for worse, were not invented by the current government.

[84]Now HSBC, with the full name seldom mentioned.

Shanghai. It was again Li Hongzhang who instigated the first Chinese-controlled modern bank some two decades later.

End of movement

If the Self-Strengthening Movement, launched in the aftermath of defeats by Anglo–French forces, had the primary purpose of shoring up the nation's military capability, then the whole enterprise lost much of its credibility, at least in its implementation, when Qing forces suffered yet another major defeat in 1894, this time at the hands of the Japanese. The First Sino–Japanese War (known in China as the Jiawu War) was fought over rivalry in Korea, hitherto a tributary state of China which Japan sought to bring under its domination — the ultimate ambition to annex not only Korea but at least the northern parts of China was but thinly veiled and indeed put into action in the Twenty One Demands of 1915 (see below), more blatantly with annexation of the Northeast Provinces in 1931, and with outright and brutal invasion in 1937. The most notable battles of the Jiawu War were on the sea, and the Qing Northern Fleet, despite better tonnage and weaponry, was completely routed, with several battleships sunk and Captain Deng drowned; the overall fleet commander Ding committed suicide in 1895. The hostilities ended with the Treaty of Shimonoseki (known in Chinese as the Maguan Treaty), which wrest Korea from China's sphere of influence, gave Taiwan to Japan as a colony, and imposed war reparations on the Qing government.

At an overall political and strategic level, the defeat brought a deepening sense of national crisis. Japan, though not a vassal, had certainly been seen as a secondary player within the ambit of Chinese influence; it had begun on a path of modernisation only in the Meiji era beginning in 1868 — some years after the Self-Strengthening Movement started. The weakness of the Qing Dynasty was laid bare for all to see, and soon many foreign powers started to encroach on China, in a wave of "Scramble for Concessions", among which we must note the concession in 1898 that leased the New Territories to the British for 99 years, with China's exercise of sovereignty regained only in 1997. The existing Qing power structure was no longer viable, and before long a tug of war would emerge between revolutionaries calling for a republic to replace the monarchy and conservatives fighting a rear-guard battle with proposals for a constitutional monarchy. Those aspects of mainstream history are not our concern here, except to note that the tone in society had markedly altered, and notions of *fundamental* changes entered the collective consciousness, at least among the intellectuals.

On the narrower front of science and technology development, one must admit that the Self-Strengthening Movement had come to a screeching halt, as far as a coherent national drive was concerned. It did not help that advocates of technological reform were often the same as advocates of constitutional reform, and were therefore viewed with suspicion by the powerful conservative faction, including the Empress Dowager. Nevertheless, many initiatives continued, notably the growth of enterprises in the private sector; ironically, the forced opening up of treaty ports had brought with it more contacts with West-

ern ideas, practices and technology. In short, although the original impetus of military modernisation had failed, industrialisation, if only as a shallow external graft, had arrived in China.

Finally, a postmortem of the Jiawu debacle is useful not just for the sake of military history, but for an important insight into the necessary conditions for new ideas and new ways of doing things — including science and technology — to take root. The naval vessels bought from Europe were indeed modern, but there was little sense of maintenance. The crew were largely untrained and ill disciplined. In short, an accompanying modern mindset was absent. Here one must mention Zhang Zhidong, who, at the same time as he pushed for arsenals and factories, also sought to preserve the traditional mindset, with the famous aphorism "Chinese learning at the core; Western learning only for use" (*zhongxue wei ti; xixue wei yong*).[85] The debate about mindsets and traditional learning naturally takes us to the May Fourth Movement.

May Fourth Movement

(The best reference is *The May Fourth Movement: Intellectual Revolution in Modern China* (Chow, 1960).)

The May Fourth Movement, so pivotal in modern Chinese history, is relevant to our topic for two reasons: (1) "Mr Science" is one of the two slogans often associated with the Movement; and (2) the fundaments of traditional culture were challenged, preparing the ground for the introduction of modern science and also raising for us the question (already touched upon in Section 3) of the philosophical and cultural underpinnings of science and technology — and whether these, in the case of China, must share some of the blame for the failure of modern science to emerge. The Self-Strengthening Movement was about armaments and factories; the May Fourth Movement was about souls and values.

However, before delving into details, it is well to clarify a point of terminology, which might otherwise be confusing. We shall (reluctantly) follow the commonly accepted if somewhat illogical convention (Chow, 1960): the umbrella term "May Fourth Movement" embraces two elements: (1) the May Fourth Incident, including what happened on that day in 1919 and in the weeks thereafter, as well as the proximate causes and the eventual impacts; (2) the New Culture

[85]This well-known saying now tends to be viewed in a negative light, as narrow-minded and typical of those who enjoyed privileges in traditional society. Bertrand Russell visited China in 1920–21, and in a speech said "the aim which Young China should set before itself [should be] the preservation of the urbanity and courtesy, the candour and the pacific temper, which are characteristic of the Chinese nation, together with a knowledge of Western science and an application of it to the practical problem of China" (Russell, 2021, cited in Chow, 1960. pp 234–235) — a sentiment that was arguably similar. Dewey, also visiting China in the same period, likewise expressed nuanced views about the extent and pace with which China should adopt Western practices. The CUHK motto "To combine tradition with modernity, to bring together China and the West" encapsulates a wish that is not altogether different. These remarks are meant to highlight the continuing relevance of the debate as to whether modernisation should be equated to (total) Westernisation.

Movement, which encompasses a loose collection of events, and importantly, publications, starting from as early as say 1915 (well before the famous date) and going into the early 1920s. The two components are of course not causally or philosophically independent, and they shared a number of protagonists; yet the two were not the same.

Context

The quarter century after the Jiawu War (1894) was a tumultuous period in Chinese history, and only the briefest[86] sketch will be given here. In 1895, a group of scholars led by Kang Youwei and Liang Qichao submitted a petition for reform. Although the petition came to nought in the immediate term, reformists were galvanised, and Kang came to the notice of Emperor Guangxu, who was willing to consider changes. Three years later the Emperor together with his supporters launched bold reforms amounting almost to a coup against Cixi behind the throne. The initiatives were crushed within months; hence the brief episode is also known as the Hundred Day Reform. The Emperor was placed under virtual house arrest by Cixi, Kang and Liang fled into exile, and six prominent leaders (including a younger brother of Kang Youwei) were publicly executed. The conservative faction consolidated its grip on power, at least for the time being.

Meanwhile, there was mounting resentment in some areas with the increased presence of foreigners, the extra-territorial rights they enjoyed, and their often grating colonial behaviour. Flood and famine added to the discontent — which erupted in 1898 in riots, first locally in Shandong, then becoming widespread, in a movement led by the Society of the Righteous and Harmonious Fists (*yihequan*) and known in English as the Boxers. The Boxers targeted foreigners (and also Chinese Christians) and officials protecting them, but were supportive of, and were supported by, the Qing government.[87] In 1900 the Boxers laid siege to the Legation Quarters in Beijing — prompting a strong military response, and a coalition army from eight nations[88] defeated the Boxers and essentially took Beijing, yet another deep humiliation for the Qing government. The image of eight different nations carving up China was seared into the Chinese mind, and would become a powerful driving force for modernisation. The thought that "this must not happen again" would be one of the principles that guide national policy, even to this day.

Two related acts of the Qing government in the period of its final death throes are relevant to our tale. The first is the establishment in 1895 of an Imperial University (more accurately the Capital Grand Academy (Jingshi Daxuetang)), which would be renamed Peking University (Beida) in 1912. This first (semi)

[86] And therefore necessarily over-simplified.

[87] It would not be entirely wrong to think of the Boxers as a group of uneducated xenophobes with no knowledge of science or even common sense (they thought bullets could not harm them) out to "Make China Great Again" and being used as pawns by the top leader.

[88] The eight nations were Japan, Russia, Britain, France, US, Italy, Germany, Austria–Hungary, listed in order of the sizes of the respective armies they deployed.

modern university was initially organised in two branches, one for classical Chinese studies, the other for Western learning — echoing Zhang Zhidong's duality of core values versus practical utility. The second was the abolition of the imperial civil service examination in 1905, signaling — years before the May Fourth Movement — that Confucian tradition was to be unseated from its hitherto unrivalled position in Chinese officialdom.

The Wuchang[89] Uprising of 10 October 1911 finally broke the Qing Dynasty. Revolutionaries took control in most provinces but Beijing and the surrounding region remained in Qing hands. Provincial representatives meeting in Nanjing in 1912 established the Kuomintang (KMT),[90] declared the formation of the Republic of China, and elected Sun Yatsen as interim President. With the Manchu court hanging on in Beijing, Yuan Shikai, who was effectively the military commander in the province, engineered a deal whereby the Qing Emperor (in fact, the mother of the child emperor together with senior officials) would transfer power to him, while the Republican government would yield to him the presidency — a deal that Sun graciously if reluctantly agreed to.[91] Only then did the Qing Dynasty end, in 1912. Yuan insisted on siting the capital in Beijing, thus starting the period of Beiyang Government. In 1915, Yuan disgracefully yielded to Japan's infamous Twenty One Demands, which, if fully implemented, would effectively make a large part of China a colony of Japan. Yuan also declared himself Emperor in 1915, in a farce that lasted less than three months. Yuan died a few months later, in 1916. The Beiyang Government held onto the north of China, going through about a dozen presidents or acting/ interim presidents until China was finally reunited (at least nominally) in 1927 by the KMT with its base in Nanjing.

Therefore, when the May Fourth Incident erupted in Beijing in 1919, the northern part of China was in the hands of the Beiyang Government, with its authority and legitimacy in tatters.

May Fourth Incident

The First World War in Europe (1914–18) was remote, but China had joined on the side of the Allied Powers in the last years of the conflict, sending more than 100,000 labourers. War ended with the defeat of the Central Powers at the end of 1918, and the Treaty of Versailles was signed in June 1919; China was among the victors, though admittedly in a small way. The negotiations leading up to the Treaty had to decide on the disposal of German possessions. Various German colonies in Africa were divvied up among the Allied powers.

[89] The three cities Wuchang, Hanyang and Hankou were administratively combined into the mega-city Wuhan only in 1927, during a brief period when the Republican government had its capital there. Thus, the uprising of 1911 is always cited in the name of Wuchang, not Wuhan.

[90] In pinyin: Guomindang.

[91] Yuan is often said to have usurped the presidency. Technically he obtained it in a deal agreed to by all sides, though he later broke important agreements.

The German concession in Shandong[92] was however to be given to Japan[93] instead of being returned to China.

Thus on 4 May 1919, a little over a month before the Treaty was eventually signed, university students in Beijing demonstrated to oppose the transfer of Shandong to Japan, and demanded that the Chinese delegation should boycott the Treaty.[94] The demonstration raised political awareness among intellectuals, and soon spread to workers in the major cities.

It must be remembered that, in the first instance, the focus of those who demonstrated and marched was territorial sovereignty. If democracy and science came into the discussion at all (and this will be discussed below in the wider context of the New Culture Movement), they were for the most part only *tools* for the purpose of saving the nation and defending sovereignty, not goals for their own sake.[95] This remark is important, for this view of science and technology remains in the mainstream among policy makers even today.

New Culture Movement

Even before the Qing Dynasty collapsed, it was already apparent that fundamental changes were needed to save the nation.[96] The more progressive thinkers became increasingly convinced that mere advancement in external hardware (*vide* the stance represented by Zhang Zhidong) was no longer sufficient; neither was mere constitutional change at the formal level. What was needed was a change of mindsets and attitudes, in other words, innovations, indeed revolutions, in the *cultural* sphere. These changes required that the assumptions and traditions of old be questioned, challenged and where necessary boldly abandoned. The New Culture Movement refers collectively to the events and initiatives that contributed to this shift in mindset.

> It was not a uniform or well-organised movement, but rather a coalescence of a number of activities often with divergent ideas, though not without its main currents.
>
> (Chow, 1960, p 5)

In modern parlance, it was a culture war,[97] which, unlike a military conflict,

[92] A legacy of German influence is Tsingtao Beer — so spelt, rather than Qingdao.

[93] Japan had entered the war on the allied side as well, principally with an eye on German concessions in China.

[94] In the event, the Treaty of Versailles (1919) was signed in June with the Allied side represented by Britain, France and the US, but the Annex showing the "Original Members of the League of Nations Signatories of the Treaty of Peace" included China in the list. The full list of signatures later appended did not include that of any Chinese official.

[95] Chow (1960, p 359) in writing of the May Fourth Movement in the broad sense, i.e., not just the events of the day, stated that "The most important purpose of the movement was to maintain the existence and independence of the nation, a goal which had actually generated all of the major reforms and revolutions in China since the latter half of the nineteenth century."

[96] The term "save the nation" apparently first surfaced in the wake of the Jiawu War; see Chow (1960, p 20).

[97] A dictionary definition is "a conflict or struggle for dominance between groups within a society or between societies, arising from their differing beliefs, practices, etc." (Dictionary.com, 2021).

cannot be assigned precise dates; nevertheless, the New Culture Movement is usually associated with the period 1915–25, with the end date fuzzier. Its beginning was described thus:

> Chen Duxius's return from Japan in 1915 and his establishment of *New Youth* magazine that fall[98] marked the start of a basic reform movement. This was reinforced by Cai Yuanpei's return from France in 1916, and by his campaign for reorganisation of Peking University in and after 1917.
>
> (Chow, 1960, p 41). Names rendered into pinyin

Chen Duxiu, by then nearly 40, had returned from studies in Japan;[99] Cai, almost ten years older, had studied in Germany before his sojourn in France. Their paths converged in 1917 when Chen became Dean of Arts at Peking University. Also at Peking University at that time were a number of people later to become famous and influential. Li Dazhao, just 30 and just returned from Japan, was the chief librarian; under his wings was a young library assistant by the name of Mao Zedong, who incidentally had been among the many youthful contributors to *New Youth*, in 1917 under a pseudonym (Chow, p 74). Lu Xun,[100] in his mid 30s, had attended medical school in Japan, but did not complete his degree, turning instead to expressions of national and social concern as an essayist, with pieces published in *New Youth* for example. By 1920, Lu Xun had become a part-time teacher at Peking University, spending the rest of his time with mid-level duties in the Education Ministry and as a writer. Hu Shih,[101] just 30, had returned from the US in 1917 to join Peking University as a professor; he had also written for *New Youth*. Among this stellar cluster of scholars, the oldest, Cai, held the highest qualification (*jinshi*) in the imperial civil service examination, sometimes likened to a doctorate, while the youngest, Hu, held a doctorate from Columbia — symbolising the transition from old to new that was their common concern. They were but the best known of a large number of intellectuals, mostly young, who were active players in the New Culture Movement.

Peking University, as one of the iconic centres of the movement, housed on its campus scholars with different points of view. Hu Shih was politically more conservative, interested in literature and trying to avoid politics.[102] To his right politically were some monarchists nostalgic for the bygone days of the Qing Dynasty. At the other extreme were Chen Duxiu and Li Dazhao, who would establish the Communist Party of China (CPC) in 1921. Cai, as president, was

[98] The magazine was initially published in 1915 under the title *Youth*, with six issues in Volume 1. Early in 1916, the name was changed to *New Youth*, but starting with Volume 2, thus clearly indicating the continuity. See Chen Wanxiong (1979, p iii). For simplicity, it is common to refer to *New Youth* for the entire series.

[99] He had been to Japan multiple times, interspersed with social and revolutionary activities back in China.

[100] Zhou Shuren is commonly known by his pen name Lu Xun.

[101] This was how he himself spelt his name; in pinyin he is referred to as Hu Shi.

[102] Hu Shih would later be ambassador to the US (1938–42), President of Peking University (1946–49) and President of Academia Sinica in Taipei (1958 till his death in 1962).

to his credit tolerant and protective of diverse views among the professors, so long as these were personal views. His attitude towards student involvement in politics was similar. Given the currency of the issue (even though it has little to do with science and technology) and since Cai Yuanpei is often held up as the role model of how a university leader should manage students and their political activities, it is of interest to recall how Chow described this situation.

> In Cai's opinion, the most important duty of a student in school was to study. He held that no relation should exist between political organisations and the school as such, but students of twenty years of age or over who were interested in politics might join any political organisation as individuals.
>
> (Chow, 1960, p 50), name changed to pinyin

It was a heady time for young activists. They pushed for the use of the vernacular in literature, and a more modern form of education. Traditional, especially Confucian, values were called into question, and Western ideas were promoted. Women's rights were advocated. With all these aspirations, it was natural that they also ventured into the political sphere; however, in this domain, inevitably divergences and fissures developed among these intellectuals, much as in society as a whole.

Mr Democracy and Mr Science

The personification of two ideals as Mr Democracy and Mr Science is often regarded as the battle cry of the May Fouth Movement. First of all, this had little to do with the May Fourth Incident. The terms were coined by Chen Duxiu in 1919,[103] when he defended *New Youth* in its third anniversary issue:

> They accused this magazine [*New Youth*] on the grounds that it intended to destroy Confucianism ....
>
> All of these charges are conceded. But we plead not guilty. We have committed the alleged crimes only because we supported the two gentlemen Mr Democracy and Mr Science. In order to advocate Democracy, we are obliged to oppose Confucianism ...; in order to advocate Mr Science, we have to oppose traditional arts and traditional religion; and in order to advocate both Mr Democracy and Mr Science, we are compelled to oppose the cult of the "national quintessence" and ancient literature. ...
>
> (Chen Duxiu, 1919, translated by Chow, 1960, p 59)

This passage makes it clear that Chen's "Mr Science" had not much to do with what we now associate with science: Chen was not advocating the study of physics and chemistry, and he certainly was not calling on the government to

[103] In January 1919, so it is likely that the marchers on May Fourth would have read it; but that is not to say that this was a major theme in the events of that day.

provide support for research; the concept of STEM would be unknown to him — he was only calling for rationality and the abandonment of superstition.[104] Though it is not our primary concern here, it might likewise be remarked that his "Mr Democracy" had much less to do with the modern neo-liberal vision of this concept than with what would later turn out to be the notions advocated by the CPC — which after all was his child.[105] The sentiment was not markedly different on the other side of the political spectrum. The Kuomintang thought of democracy as "discipline" and science as "organisation" (Chow, 1960, p 346).

Summary

In short, the May Fourth Movement was a Renaissance for China (Chow, 1960, p 3), and provided the soil on which science could grow. In a sense, it was a watershed that marked Chinese society turning its collective attention from the past to the future. Perhaps not too much should be read into the specific terms "Mr Democracy" and "Mr Science", which as catchy phrases have gained more attention than they deserve. The ramifications for political developments and the course of history were immense, but not our immediate concern here.

If the May Fourth Movement is a launch pad for the progress of the nation all the way to the present, it is interesting to note that "[a]t the end of the May Fourth period, John Dewey[106] ventured to predict that China might achieve in ..." (Chow, 1960, p 366)

> ...a century or so the intellectual, scientific, industrial, political, and religious progress for which the rest of the world has taken several centuries. It cannot, like the United States, make the change with plenty of elbowroom, but must accomplish it in a civilization crowded with traditions and superstitions as well as with people.
>
> (Dewey, 1921, cited in Chow, 1960, p 366)

The reference to scientific and industrial progress makes this prediction especially relevant to our purpose here. It has been almost exactly a century since these words were written, and one must give Dewey credit for his prescience both about the speed of progress and about the objective challenges.

Study abroad

Another significant development ran quietly in parallel: students going abroad and bringing back knowledge from the West, including of course science and technology.[107] The above account of the May Fourth Movement has already

[104] This point is elaborated in Chen Wanxiong (2007).

[105] Though there was a falling out later and he was expelled from the Party in 1929.

[106] It may be recalled that Dewey, the teacher of Hu Shih, spent some time in China around this period, and was a close observer of the May Fourth events.

[107] In fact, more science than technology, since few of these students gained much experience outside of academia. Engineers who returned to Taiwan from the 1980s onwards were a notable exception; see below.

cited a number of returnees, though these were not educated in science and technology; the one exception in that list is Lu Xun, who, despite his later fame as a writer, had started his education in Japan in the field of Western medicine.

Japan, because of the proximity, was an important destination,[108] especially in literature, social science, law and military studies. Many commanders in the early part of the 20th century were trained in Japan; Chiang Kai Shek (Jiang Jieshi) attended a military academy there in 1908. Among the few notable examples in science and technology one can count Su Buqing, a graduate of Tohoku Imperial University (first degree 1927, PhD 1931) who was one of the first generation of leaders in modern mathematics in China.[109]

The first known case of a Chinese student getting an American degree was Yung Wing[110] (Rong Hong), a native of Zhuhai educated at a missionary school in nearby Macao (City of Zhuhai, 2020). The head of the school, a Yale graduate, facilitated Yung's entry in 1850 to Yale,[111] from which he gained his degree four years later; he studied classics, and confessed to difficulties with calculus (Yung, 1909, p 37).[112] Upon graduation, he was "determined that the rising generation of China should enjoy the same educational advantages that [he] had enjoyed; that through western education China might be regenerated, become enlightened and powerful" (Yung, 1909, p 61) — this sentiment was characteristic of many generations of students going abroad to study.

Upon return to China,[113] Yung started a modern school in Zhuhai, dabbled in translation, law and commerce, advised Zeng Guofan on the purchase of machinery for producing armaments,[114] and for this purpose led a delegation to the US; most importantly, he persuaded the Qing government to start an official scheme of sending students abroad, with four cohorts starting in 1872 and totalling 120 students.[115] The young students (some pre-teen) lived with host families, attended high school and then entered university, with Yale being one of the destinations. The scheme faltered a decade later, in part because Qing officials became wary of the impressionable young men becoming totally Westernized. Many of the returnees were sidelined, though a number made

[108] At least up to the start of widespread hostilities, say in the mid-1930s.

[109] Upon return to China, he first taught at Zhejiang University, and was later transferred to Fudan. Both have become important centres for mathematics, especially differential geometry, thanks to the leadership of Su and of his disciples.

[110] His given name should be pronounced *wang4* in Cantonese, see, e.g., *Multi-function Chinese Character Database* (CUHK Humanum).

[111] Partly for this reason, Yale has developed a tradition of engagement with China. The Yale–China programme has an office in CUHK.

[112] Readers may be surprised that a student majoring in classics was obliged to study both differential and integral calculus.

[113] In his autobiography, Yung (1909, p iii) speaks of his "metamorphosis in ... inward nature", coming back as if "from a different world", yet at the same time with "neither [his] patriotism nor [his] love of [his] countrymen ... weakened".

[114] Having seen the cruelty and corruption of Qing officialdom, Yung was sympathetic to the Taiping rebels; yet paradoxically he also had high regard for Zeng, who had crushed the rebels.

[115] One of the 120, from the same village and clan as Yung Wing, had a grandson CT Yung who would be head (in those days called President) of Chung Chi College at the time when CUHK was formed, and would also be the first Pro-Vice-Chancellor of CUHK.

important contributions. The best known is Zhan Tianyou, another native of Guangdong, who gained a degree from Yale in civil engineering and upon his return to China was responsible for the development of China's own railroads without foreign involvement (and hence without foreign control). An interesting and comprehensive account of these 120 students can be found from the compilation *Chinese Educational Mission Connections 1872–1881* (CEM, 2021).

The flow of students to the US, in particular, grew with the establishment in 1909 of the Boxer Indemnity Scholarship Fund[116] or Gengzi Peikuan, for short Gengkuan. Over a thousand scholars were funded through this scheme in the ensuing decades. There was a similar but smaller scheme in the UK, and also in France and Japan. The scholars going overseas gradually included a significant number pursuing advanced degrees, in many cases doctorates. The returnees during the Republican era perhaps did not immediately engender a rise in the level of science and technology *per se*, but would have a profound effect in developing universities and training the next generation of students, many of whom eventually making significant contributions in the second half of the 20th century. One anecdote would serve to illustrate the pattern of intellectual genealogy.

CN Yang, one of the first Chinese to win a Nobel Prize[117] and a Distinguished Professor-at-Large at CUHK, recalled that in his student days at Southwest Associated University during the war years,[118] the teachers in physics and mathematics included Wang Zhuxi (statistical mechanics, Cambridge PhD 1938), Wu Tayou (quantum mechanics, Michigan PhD 1933), Xu Baolu (statistics, London U PhD 1938), Ma Shijun (electrodynamics, Cambridge PhD 1941), SS Chern (mathematics, Hamburg PhD, 1936), and of course his own father Yang Wuzhi (mathematics, Chicago PhD, 1928); see Yang and Shi (2014).

Jumping ahead of our story, we should briefly cite later developments in this story. There was a wave of going abroad to the USSR in the 1950s and early 1960s, almost exclusively in science and technology. One should not forget the very significant number of students from Taiwan who in the same period went on to the US in particular,[119] many in science and technology, especially electrical engineering. The return of some of these from the 1980s onward, when the Taiwan economy started to take off and the political environment became more open, was responsible for the rise of Taiwan as a significant global player in semiconductors.[120] Of the teachers in science and engineering at CUHK, the vast majority have degrees from abroad. And on the mainland, starting from a trickle in the early 1980s, studying abroad has become an important channel for higher education, and increasing numbers are returning to work in China

[116]The Scholarship was funded out of the indemnity paid to the US as a result of the settlement of the Boxer Rebellion. It is often loosely referred to simply as the Boxer Scholarship.

[117]Physics, 1957, shared with TD Lee.

[118]There are interesting first-hand documents and photographs from those days in the CN Yang Archive at CUHK.

[119]In those days, the male students were not allowed to leave until they had completed military service, so the outbound students were almost exclusively postgraduate.

[120]Currently, the world's largest semiconductor foundry (or fabrication factory, "fab" for short) is Taiwan Semiconductor Manufacturing Company Limited (TSMC).

(*haigui*), significantly enhancing the science and technology capacity.

Another side story of study abroad should also be mentioned, even though its direct and ostensible impact on science and technology was minimal. In 1920, Deng Xiaoping, then just 16, arrived in France on a work-study programme.[121] Also there was Zhou Enlai, who recruited him into the CPC, and Nie Rongzhen, later Marshal in the People's Liberation Army (PLA), who was destined to play an important role in the development of the atom bomb (see Section 11). However, the point to be made here is this: One might well be given to wonder whether, without the benefit of that international exposure, Deng would have been the outward-looking leader that he was, and whether there would have been the reform and opening up starting from about 1978 — which would turn out to be directly responsible for the enormous advances in science and technology in the last four decades.

10 The Needham question

(I am indebted to Dr FC Chen for much of the material in this section.)

This point in the chronological account is the appropriate place to bring up the question (already touched upon in Section 2) "Why did modern science fail to emerge in China?", or "Why did Chinese science lag behind Western science?" Although often associated with the name of Needham, the query was first raised earlier.

Raising the question: Ren Hongjun

The gap in the level of science was already recognised by Xu Guangqi in the late Ming, though there was no sense of urgency in looking for the cause until the whole country fell into an abyss of humiliation and despair in the second half of the 19th century. Here we pick up the tale with the students pursuing studies abroad in the early Republican years. Cornell University was a destination for quite a number of Chinese students; Hu Shih and the renowned linguist Zhao Yuanren had both studied there.[122] In 1914, a group of Chinese students formed a Science Society of China, in which the most active member was Ren Hongjun (HC Zen).[123] While the question of a fundamental lag in science was

[121] He mostly worked, and apparently did not much study. There is little record, after his rise to prominence, that he ever spoke in French.

[122] Much later, in the 1960s, Lee Teng-hui would also be a student at Cornell.

[123] Ren had an interesting career, starting with the first level (*xiucai*) in the imperial civil service examination system, studying chemistry in Japan, engaging in revolutionary activities in the final years of Qing rule, serving in the office of the President when Sun Yatsen was briefly in power, then going abroad again, first to Cornell and later to Columbia. Armed with a master's degree, he returned to China, and became a professor at Peking University. In the 1930s, he was President of Sichuan University, and later served as Secretary-General of Academic Sinica. Apart from chemistry, he was interested in the history of science, in the belief that only a proper understanding of the historical processes could foster a scientific spirit. He was a close friend of Hu Shih: they were high school classmates; they both attended Cornell, though without overlap; and then they both went on to Columbia.

obviously in the minds of many Chinese students, it was apparently Ren (1915) who put it forcefully into print, in an article "On the cause why China had no science", published in the inaugural issue of the journal *Science* (*Kexue*) which he founded.[124]

Several remarks can be made about this article. (1) The investigation was obviously motivated by the mission to "save the nation". (2) Although Ren referred to "science" rather than "modern science" (which is how we would now put the question, to acknowledge that pre-modern science not only existed but was robust in China), he implicitly meant the latter, since he wrote that Western science had been around only 300 years. (3) His tentative answers to the question were the lack of scientific method, especially the inductive process based on experimentation, and a tendency to vague abstractions rather than precision, as well as a lack of curiosity about causes. (4) In this article, and at greater length in later ones, he pointed to the scientific spirit[125] and its apparently weakness in China. (5) There is much to be said for Ren's point of view, but the writings on his part and on the part of other contributors to the debate were largely at the level of opinions and conjectures — ironically the very scientific spirit and respect for evidence that they pointed to were not yet to be found in their own practice as putative historians. (6) He wrote in elegant classical Chinese (as befitted a *xiucai*) — the push for the vernacular form was just beginning. But an interesting question is whether the somewhat vague and loose arguments in this article[126] (the same weakness that Ren criticised in ancient Chinese investigations into nature) were intrinsically tied to the classical style of expression.

Needham

The person

Joseph Needham (1900–1995), known in China as Li Yuese, started his career as a biochemist in Cambridge. During the Second World War, he was sent by the Royal Society[127] to Chongqing (the wartime capital) to head an office for science cooperation. There he developed his interest in early Chinese science, already kindled by a Chinese student he had in Cambridge, Lu Gwei-djen (Lu Gweizhen) — later to become his lifelong collaborator and, in old age, his second wife. For us, the best introduction to Needham the person can be found in the citation for his honorary doctorate from this university (CUHK, 1983).

[124]The journal ran into difficulties in the early 1950s, was briefly revived in 1957, still under Ren, and then stopped again in 1960 for political reasons. It was relaunched in 1985, by then as an official publication, and under the editorship of Zhou Guangzhao, a distinguished theoretical physicist who was one of the youngest members involved in the atom bomb project, and who later rose to become President of CAS and then one of the Vice Chairmen of the National People's Congress.

[125]Apparently Ren was the first to use the term *kexue jingshen*.

[126]The article, in typical classical style, appealed to allusive and correlative reasoning. In arguing that science needed both deduction and induction, he made the parallel with a chariot needing two wheels and a bird two wings.

[127]He went in 1942, after being elected FRS in 1941.

His fame derives not from biochemistry but from his monumental study of early Chinese science. Needham was a scientist and a Sinophile.[128] He also had Marxist inclinations — by no means rare among British intellectuals in the 1930s.[129] However, he was not a Marxist in the sense of supporting the dictatorship of the proletariat; rather, he was receptive to the Marxist view that the course of history was strongly influenced by the economic and social structure of society, though he did not subscribe to the idea of universal historical laws.[130] The more he worked on Chinese history and civilisation, the more he became enamoured of Daoist philosophy. His Marxist and Daoist tendencies would colour his views about science in China.

The *magnum opus*

Early assessments of science and technology in China suffered from a failure to sufficiently distinguish between traditional science and modern science. Even Ren, who certainly had this distinction in mind, did not emphasise it. There was therefore a tendency, especially among Western scholars, to assume that Chinese science[131] had *always* lagged behind European science. This assumption was in part due to ignorance, but it would be wrong to pretend that there was not a deep-seated racial prejudice: that some civilisations were intrinsically inferior ("witness their inferior science!"), or, with a slight twist, that tropical and humid climates were not conducive to higher mental processes (applied at least to the case of India if not China); "racism" would be a just label, and Euro-centrism a kinder euphemism. Such a belief would give an easy answer to the question at hand. Needham's multi-decade project showed, beyond a doubt, that *early* Chinese science could boast of a host of achievements, in many cases leading the West — and thereby extinguished any racial (or climatic) argument that would have implied the same gap through all of history.[132] This definitive demonstration is important, for there remains to this day a resistant strain of racism which would claim that non-White science cannot — or cannot be allowed to — match or surpass Western science.

The life-long work was published in *Science and Civilisation in China* (Needham, 1954), here abbreviated as *SCC*. The publication is notionally in seven Volumes, with the first published in 1954; however each of several Volumes consists of multiple Parts in individual bindings (and published at different times),[133] so the series really comprises over twenty substantial books.[134] The

[128] The best known of his biographies is entitled *The Man who Loved China* (Winchester, 2008).

[129] See for example the famous story of "the Cambridge Five" who spied for the USSR.

[130] "...I have never been sympathetic to that other trend in Marxist thinking which has sought for a rigid and unitary formula of the stages of social development which all civilisations 'must have passed through'." (Needham, 1969, p 192).

[131] And also science in other non-European civilisations.

[132] "From the beginning I was deeply sceptical of the validity of any of those 'physical-anthropological' or 'racial-spiritual' factors which have satisfied a good many people." (Needham, 1969, p 191).

[133] For example, Volume 5 is divided into 13 Parts.

[134] This slightly confusing nomenclature derives from two reasons. First, he and his collabor-

series continued to be augmented by Needham's collaborators after his death.[135] Even professional historians of science would find the entire series daunting; the tomes are more like source books of primary research. A more accessible version is the *The Shorter Science and Civilisation in China* (Ronan, 1978),[136] here abbreviated as *SSCC*, which is a precis of *SCC*.[137] Though "shorter", *SSCC* still runs to five volumes.

SCC, by its very meticulous examination of primary evidence as well as well-established literature, paints a picture of traditional Chinese civilisation (from antiquity to medieval times) that was rich in inventions and in science. Although Needham the Sinophile was given to exaggerations (e.g., in claiming that some European inventions were derivatives when they were just as likely to have been independent, and in giving excessive credit to vague statements in ancient Chinese texts as precursors of modern science), it is nevertheless true that, even with such excesses discounted, one cannot get away from the conclusion that traditional Chinese science, as an example of *pre-modern* science, i.e., in comparison with Europe before the Scientific Revolution, was robust, in a nontrivial number of domains even leading.

This conclusion does not answer the key question at hand, but only tilts the emphasis to *modern* science, and by implication, to the question placed side-by-side with its obverse: Why did modern science arise in Europe but not in China, when the latter was (apparently) by no means lagging behind, say in the 16th century?

Needham's thesis

Needham did not, in fact, directly address in *SCC* the question that came to bear his name — *SCC* was a compilation of evidence rather than any excursion into hypotheses. Rather, his answer to the question was contained in lectures given over the years and recorded in essays such as those collected in *The Grand Titration* (Needham, 1969). Here we draw in particular on the essay "Science and society in East and West", first published in 1964 and reprinted in Chapter 6 of *The Grand Titration*.

As already mentioned, Needham was inclined to seek explanations in the social and economic structure: "The answer to all such questions lies, I now believe, primarily in the social, intellectual and economic structures of the different civilisations." (Needham, 1969, p 190). Needham pointed to the different kinds of feudalism in Europe and in China.

> For the purposes of the historian of science, therefore, we have to be on the watch for some essential differences between the aristocratic military feudalism of Europe, ... and those other kinds of feudalism

ators kept adding to each topic, for example adding to Volume 5 after Volume 6 was already out. Moreover, it seems that there was an original agreement with Cambridge University Press for a certain number of "Volumes", which this stratagem helped to circumvent.

[135] For example, Parts 11, 12, 13 of Volume 5 were published in 2008, 2004, 1999.

[136] Sometimes the authorship is attributed to Ronan and Needham.

[137] Not covering additions to *SCC* after the death of Needham.

> ... which were characteristic of medieval Asia. From the point of view of the history of science we must have something at any rate sufficiently different from what existed in Europe to help us solve our problem.
>
> (Needham, 1969, pp 191–192)

He went on to quote Wittfogel's[138] idea of of "bureaucratic feudalism" in Asia, which was explained as (Needham, 1969, p 193) "the growth of a State apparatus fundamentally bureaucratic in character and operated by a non-hereditary elite upon the basis of a large number of relatively self-governing peasant communities, still retaining much tribal character and with little or no division of labour as between agriculture and industry", the social order being justified on two counts: defence and public works. The emperor exercised authority not through feudal lords, but through a non-hereditary civil service or "mandarinate". He went on to say

> ... the Asian "bureaucratic feudalism" at first favoured the growth of natural knowledge and its application to technology for human benefit, while later on it inhibited the rise of modern capitalism and of modern science in contrast with the other form of feudalism in Europe which favoured it .... A predominantly mercantile order of society could never arise in Chinese civilisation because the basic conception of the mandarinate was opposed ... to the value-systems of the wealthy merchants. Capital accumulation in Chinese society there could indeed be, but the application of it in permanently productive industrial enterprises was constantly inhibited by the scholar-bureaucrats, as indeed was any other social action which might threaten their supremacy. Thus, the merchant guilds in China never achieved anything approaching the status and power of the merchant guilds of the city-states of European civilisation.
>
> (Needham, 1969, p 197)

Evaluation and a more viable alternative

There is some truth in Needham's description of Chinese society, but to offer these observations as an explanation for the failure of modern science to emerge would seem to be very much off the mark. Needham's error is rooted in his conflation of science and technology. Much of what he described as achievements in pre-modern China (such as the examples cited in Sections 4 and 5) were really technological rather than scientific, even though his monumental work was entitled "science and civilisation" rather than "science and technology". His thesis might have some merit if offered to account for the weakness or belated rise of modern *industries* in China.

All this becomes clear when we examine the other side of the coin (see the reference to Spence and Sivin in Section 2): the rise of Europe after the

[138] " ... a more or less orthodox Marxist in pre-Hitler Germany" (Needham, 1969, p 193).

Middle Ages. There can be little doubt that the conceptual break came with the *Scientific* Revolution, with key names such as Bacon and Descartes in terms of methods of science, and Copernicus, Galileo, Kepler and Newton in terms of actual breakthroughs. It would be very far-fetched indeed to claim that the "mercantile order of society" or "productive industrial enterprises" (*ibid*) has much to do with these giants who, of course together with many of their comrades, collectively brought Europe into scientific modernity.

To seek reasons for the emergence of modern science in Europe would be a huge task in itself, and one must start with the recognition that there will not be sharp and unique answers. A modern treatment, keeping the contrast with China implicitly in mind, can be found in Chen (2021);[139] a good overview is found in the relatively brief Introductory Remarks (*ibid*, pp 4–34). The many factors that one can point to would surely include the legacy of Greek philosophy (to a large extent transmitted through and enhanced by the Arabic world), including Platonic ideals, Aristotelian logic, Pythagorean and Euclidean mathematics, and a tradition of curiosity and of seeking causes and laws. It is clear that Kepler's ellipses and Newton's point masses belong to the Platonic world — to which any notions of social or economic order are surely irrelevant. Indeed, Ren had already written about the scientific spirit. One must pay attention to this cluster of factors in thinking about this important transition in European history — and in seeking reasons for the failure of modern science to emerge in China.

Nevertheless one could try to advance a small twist to Needham's thesis, and thereby to arrive at a factor which might have some contemporary relevance. A capitalist or mercantile society is decentralised and pluralistic. Different individuals strike out in multiple (intellectual) directions, in their multifarious pursuits — some of which might lead to breakthroughs. A bureaucratic society tends to be more monolithic, closely adhering to a single agenda. This remark should not be forgotten in the present age, when over-emphasis on large projects and fashionable directions threatens to sideline genuine innovation.

11 From the Republican era to the first three decades of PRC

(I am indebted to Dr FC Chen for much of the material in this section.)

The Republican years under Chiang

After Sun Yatsen died in 1925, Chiang Kai Shek, having consolidated power in the KMT, launched a Northern Expedition in an attempt to quash the warlords and unify China. The Communist Party of China (CPC), hitherto allied to

[139]The author Chen Fangzheng (FC Chen) is one of the key contributors to a 3-unit GE course in CUHK on science and technology in China, from which much of the content of this article is drawn.

KMT,[140] was purged in 1927, sowing the seed for civil war. The KMT controlled south China, with the capital in Nanjing. There was a respite of only a few years, before Japan annexed northeast China in 1931 and launched all-out invasion in 1937. Victory over Japan in 1945 was immediately followed by civil war, with resolution only in 1949 when the PRC was established. Obviously there was little opportunity for science and technology to grow in this period.

Nevertheless, scientific capacity grew with the number and quality of universities. Academia Sinica was established in Nanjing in 1928.[141] These institutions benefited from the small stream of scholars who had gone abroad and then returned. The level of science education in the best universities quickly caught up with international standards, at least in those domains where sophisticated instrumentation was not an obstacle.

A jewel was Southwest Associated University (Xinan Lianda), a temporary and ad hoc amalgamation of Beida, Tsinghua and Nankai, which had all relocated to Kunming in Yunnan when the Japanese invaders occupied northern China and threatened the central provinces. During the eight years of its life (1938–1946), an unprecedented constellation of leading scholars (not just in science and technology)[142] trained an equally unprecedented group of bright students, many of whom would later make important contributions globally (e.g., Nobel Prize winners TD Lee and CN Yang) and nationally (e.g., key members of the team that developed the atom bomb many years later, and over a dozen Academicians) — despite harsh condition, scarcity and air raids.[143]

First three decades of PRC

The establishment of the PRC in 1949 ushered in an initial period of relative stability, though political movements beginning in the 1950s began to take their toll on intellectuals regarded as Rightists, and policies characterised by a surfeit of enthusiasm and a disregard for rationality[144] wrecked the economy. This was nothing compared to the devastation of the Cultural Revolution (starting 1966), in which universities and intellectuals — in other words some of the most important elements of science and technology capacity — suffered the greatest damage, though it must not be forgotten that some segments of the leading universities were among the perpetrators of chaos and destruction.

[140] Many do not realise that Mao Zedong, Zhou Enlai, Zhu De and Deng Xiaoping had all been members of the KMT, or that Chiang had in the same period sent his eldest son (years later his political successor in Taiwan) to USSR, from which he would return only after a dozen years, with a Russian wife.

[141] Academia Sinica relocated to Taipei in 1949, while on the mainland it morphed into the Chinese Academy of Sciences (CAS).

[142] Including the historian Qian Mu, who would later be the founder of New Asia College.

[143] TD Lee (private communication) developed the knack of doing calculations with his finger "writing" in air, because paper was precious. Many reminiscences are recorded in biographies, e.g., those of Yang. Some first-hand material can be found in the CN Yang Archive at CUHK.

[144] For example, attempts at steel production by backyard ("*tu*") methods and at increasing rice yields per hectare by astonishing multiples — which was unsurprisingly "achieved" by fraudulent reporting.

Nevertheless, there were notable achievements, especially in major national projects. Some of these are sketched below, starting with "Two Bombs, One Satellite" (*liangdan yixing*). The two prongs were seen as parts of one single national strategy with Zhou Enlai leading a coordinating group of vice premiers and ministers. The terminology also evolved. Originally, *liangdan* referred to nuclear bombs (*yuanzidan*, including both A-bomb and H-bomb) and the missile (*daodan*); later it came to mean the A-bomb and the H-bomb as two items, with the missile lumped with *yixing* — as would be suggested by the standard English translation.

Nuclear weapons

Nuclear weapons are now an important piece on the geopolitical chess board, hopefully deployed only in deterrence and not in actual use.[145] The dates for the first successful tests of the fission and fusion bombs[146] by the five major powers (the Permanent Members of the UN Security Council)[147] are as follows.

Nation	Fission	Fusion
US	1945	1952
USSR	1949	1953
UK	1952	1957
France	1960	1968
China	1964	1967

Table 2: Dates of first explosion of nuclear device

Why did China feel a strong need for the bomb, when there were urgent and competing demands in society? How did China manage to achieve the huge scientific and technical challenge, when the country was so poor[148] and the pool of scientific talents so small? This makes for an interesting case study into the conditions necessary for (at least some aspects of) science and technology development. A comprehensive reference is *China Builds the Bomb* (Lewis and Xue, 1991).

Upon the conclusion of World War Two, Korea (formerly controlled by Japan) was occupied by the Soviet Union and the US. Civil war between the North

[145] Of course, the only cases of actual use were the two bombs dropped by the US on Japan in August 1945, when the outcome of World War Two was no longer in doubt.

[146] Fission bombs, conventionally called "atom bombs" or "A-bomb", work by splitting heavy nuclei such as uranium. Fusion bombs, conventionally called "hydrogen bombs", "H-bombs" or "thermonuclear bombs", work by fusing light nuclei such as hydrogen. The latter is many times more potent.

[147] At the time, the Chinese seat was taken up by the KMT government in Taiwan. The USSR of course no longer exists as such. British scientists were involved in the Manhattan Project; the date 1952 here refers to the independent British effort.

[148] In 1960, per capita GDP in China was USD 90, compared with USD 3,000 for the US (World Bank, 2021a).

and the South broke out in 1950 and US forces[149] joined on the side of South Korea. The front lines shifted back and forth, and at one point US forces were pushing towards the Yalu River bordering China, whereupon, in 1950, less than one year after PRC was established, Chinese forces[150] crossed the Yalu to fight alongside the North Koreans, pushing the better equipped US forces back to a stalemate at the 38th parallel. An armistice was signed in 1953. Apart from worries about China being invaded,[151] there was fear that the US might use nuclear weapons — there were overt threats, and the US President had to rein in his theatre commander. Thus, there quickly developed a consensus among the Chinese leadership that national security required nuclear deterrent capabilities; the decision was made in 1955 to launch a top-priority project to build the bomb.

Name	Born	Training	Mentor
Wang Ganchang	1907	PhD Berlin 1934	Meitner
Guo Yonghuai	1909	PhD Caltech 1943	von Karman
Qian Sanqiang	1913	PhD Paris 1940	Irene Joliot-Curie
Peng Huanwu	1915	PhD Edinburgh 1945	Born
Cheng Kaijia	1918	PhD Edinburgh 1948	Born
Deng Jiaxian	1924	PhD Purdue 1950	Belinfante
Zhu Guangya	1924	PhD Michigan 1949	Wiedenbeck
Yu Min	1926	BS Beida 1949	Zhang Zongsui
Zhou Guangzhao	1929	BS Beida 1951	Peng

Table 3: Key leaders of nuclear weapon project

The careers of the notable scientists (mostly physicists) pivotal to the bomb project (Table 3)[152] reveal much about the progress of science and technology capacity over several generations. A first generation of returnees (not shown) had helped to establish credible departments at Beida, Tsinghua, Zhejiang, and later Southwest Associated University, where those listed here obtained very good undergraduate education. All except the last two went on to top graduate schools abroad, mentored by the leading scientists of the age.[153] The younger ones were trained domestically: Yu did his BS in Beida, and went on to graduate school in Tsinghua under Zhang Zongsui; he was recruited to CAS, where he

[149] In the name of the UN, which the Soviet Union failed to veto because at the time it was boycotting the UN.

[150] Technically, it was an army of volunteers rather than the regular PLA.

[151] The worries were understandable — in the 110 years up to 1950, China had seldom been free from foreign armies on its land.

[152] There is an official list of 23 heroes for the bomb and satellite projects; the names in Table 3 are the main ones for the bomb.

[153] Meitner was (together with Frisch) the first to understand nuclear fission; Irene Joliot-Curie was the daughter of Marie Curie and herself a Nobel Laureate; Born was one of founders of quantum mechanics and a Nobel Laureate (and my doctoral supervisor's supervisor's supervisor). Belinfante, though less known to the general public, has the energy-momentum tensor in electromagnetism named after him. Wiedenbeck was the author of a widely used text on experimental techniques.

was mentored by Peng. Zhou did his BS also at Beida, and went on to graduate work under Peng; later he went to Dubna for research.[154] The system of higher degrees was not yet established, so neither Yu nor Zhou formally obtained a master's degree, let alone a doctorate. Guo was not a nuclear physicist. His expertise was mechanics (his contribution was to characterise the explosion) and his mentor, von Karman, was the undisputed world authority in aerodynamics.

Nevertheless, one must acknowledge a significant gap. In terms of contributions to basic science, these national heroes could not compare with their counterparts associated with the Manhattan Project, e.g., Oppenheimer, Bethe, Fermi, Lawrence, Bohr and Peierls, or even Feynman, who was then a very young man.[155] This observation illustrates one remark to which we shall return: truly original science is one major step beyond achievements such as developing nuclear bombs after others had already done so — a point often not appreciated by the public.

The US had accused the Soviet Union of having stolen nuclear secrets,[156] but there was no such allegation in the case of China, if only because no Chinese scientist had ever been close to the Manhattan Project. Indeed, in the 1970s Deng Jiaxian confirmed to CN Yang, his friend from childhood, that the atom bomb was built without foreign help,[157] a statement that moved Yang to tears (Yang, 2021); note that Soviet assistance had been withdrawn across the board in 1960. For the H-bomb, the situation was even more plain — the Chinese design, mainly due to Yu, was different in significant respects.

However, it must not be thought that nuclear physicists did all this alone. Making the bomb was a huge national and multidisciplinary effort: geological surveys for uranium, mining for ores,[158] chemical extraction of uranium, isolation of the tiny proportion of U-235 (the active isotope) by gas diffusion, as well as assembly into a bomb. The tasks were challenging, especially given the low level of technology throughout the country, and the state of the economy at the time. A nontrivial percentage of national GDP had to be committed, with belt-tightening in other sectors, made possible by a strong will in the country and especially within the CPC that foreign armies must never be allowed on the soil of China again. Policy directives came from the State Council, and the whole project, spread over many laboratories, was placed under military coordination, with Marshal Nie Rongzhen in charge.[159] The successful test of the A-bomb in 1964 was met with jubilation, and was followed by the H-bomb

[154] Zhou would later become President of CAS and upon retirement was elevated to vice-chair of the National People's Congress (NPC).

[155] I have the good fortune to know the youngest in each list: Feynman was one of my teachers (Feynman, 2005, p 252) and Zhou Guangzhao had visited CUHK multiple times, and was awarded an honorary doctorate in 1991. My path also crossed with Peierls' many years later (Peierls, 1991, p 40).

[156] And had consequently executed the Rosenbergs for spying.

[157] There was a rumour that the American physicist Joan Hinton was involved. Hinton was living in China at the time, working as a dairy farmer.

[158] In these domains the geologist Li Siguang was a leading figure.

[159] The natural comparison would be General Groves, who commanded the Manhattan Project. Groves was a 3-star; Nie was the equivalent of a 5-star.

only three years later.[160]

Rockets and satellites

The nuclear weapons are always mentioned in the same breath as the satellite (*liangdan yixing*); actually the latter involved rockets and missiles as well, and gave birth to both the current space programme and also long-range missiles. Although a number of scientists were also cited as national heroes, one singular figure both led the science and groomed the team of scientists for the project.

Qian Xuesen (1911–2009) received his undergraduate education in Jiaotong University, and went to the US on a Boxer Indemnity Scholarship, first for a master's degree at MIT and then to Caltech where he received the PhD in 1939 under the legendary von Karman, the world's foremost expert in aerodynamics and in the nascent field of rocket science. Caltech under von Karman's leadership became a mecca in these subjects — that is the reason why Jet Propulsion Lab (JPL) was created nearby and is managed by Caltech. Qian was one of von Karman's star students. At the end of war, Qian most unusually gained the rank of Colonel in the US Army,[161] and was sent to Germany to assess its rocket science and to recruit German scientists. He returned briefly to China to get married, and then took up appointments in the US, first and briefly at MIT, and then to a named chair at Caltech in 1949.[162]

The atmosphere soon changed. With civil war ended in China and a degree of stability restored, Qian was thinking about visits back home; it would not be surprising that he was interested in finding out what communism was all about, and he had attended a few meetings of left-wing groups in the US. But by 1950, China and the US were at war over Korea, and McCarthyism was running amok in the US. Even Oppenheimer came under suspicion and had his security clearance revoked. Qian was questioned, but his stance was clear: he was not a communist; he was fond of the US where (until these troubles) he was treated with respect, but he had an even stronger affinity for his own country. If he had hitherto only pondered on the possibility of returning to China for a visit, his treatment at the hands of the FBI tipped the scale. He was ordered deported (which did not require a judicial process) but at the same time confined to Los Angeles. He was finally allowed to leave in 1955,[163] sailing for Hong Kong and returning through Lowu.[164] During the period of his house arrest, he wrote an important book on control theory, which was to become the focus of his scientific interest (rather than aerodynamics) in the second half of his career.

[160] Thus, China was the 5th to acquire the A-bomb, but overtook France to become the 4th to have the H-bomb.

[161] He was not a US citizen, not even a permanent resident.

[162] Named chairs were rare in those days. Even in the 1960s, among the physics professors at Caltech only the two Nobel Laureates had named chairs.

[163] Probably in exchange for US airmen shot down and captured during the Korean War.

[164] So he must have passed our campus en route, though only Chung Chi was at this site in 1955.

Qian's life story is very well known in China. A good English-language source is *Thread of the Silkworm* (Chang, 1995).[165]

Back in China, Qian put up a proposal to establish an air defence industry, which essentially became the blueprint for the development of the sector. In 1957, he was appointed deputy director[166] of the 5th Academy (*wuyuan*) under the Ministry of Defence.

The main milestones were: short-range missiles in 1960, missiles carrying nuclear weapons in 1966, and the first artificial satellite (Dongfanghong) in 1970. To put these into perspective, the first artificial satellite was the Soviet Sputnik in 1957, followed one year later by the US Vanguard; so China was more than one decade behind. Manned spaceflight began only in 2003, over 40 years after Gagarin (USSR) and Sheppard (USA) had taken to space in 1961.

The satellite project (and also the H-bomb part of the nuclear weapon project) ran into the Cultural Revolution. Military sites escaped the worst of the turmoil[167] but scientists, regarded as "elites" who had drifted from the true path of revolution, in general did not fare well; several in the list of recognised heroes were persecuted. Qian Xuesen was given special protection and came through unscathed. That upheaval must be among the reasons why progress towards manned spaceflights was so much delayed.

The bombs and satellite project is hailed in China as huge achievements; the highest accolades were accorded to the heroes. It was indeed a major step forward for scientific and technological capabilities of this sort, namely the ability to replicate what a handful of other nations had done some years earlier, admittedly starting from a huge disadvantage; however, little of this was truly innovative.

Incidentally, aviation technology was not pushed as hard as space science. It was said that aeronautics was not "high technology". More realistically, China feared a nuclear attack and needed deterrents; it did not fear a ground war even when the other side had superior air power. But perhaps most practically, there was not yet much domestic demand to justify an aviation industry — until now.

Laser

The laser[168] is now a common device; every teacher uses it to point. It works by herding photons, in other words the "bits" of light, so that they act together in lock-step rather than independently. The idea of stimulated emission (the S and E in LASER) was first proposed theoretically by Einstein in 1917. In 1951 Townes in the US and independently Prokhorov and Basov in the USSR achieved

[165] The author, Iris Chang, became even better known for her next book, on the Japanese atrocities in Nanjing during the Second World War — a story so devastating that it drove her into depression and suicide.

[166] The director was an administrator, and Qian was in charge of all R&D.

[167] In fact, towards the end of the Cultural Revolution, the army was called upon to restore a semblance of order in the nation.

[168] As an acronym for Light Amplification for Stimulated Emission of Radiation, the word was written as "LASER" originally; with frequent use and familiarity, it became a word in its own right, and is now usually rendered as "laser".

stimulated emission with microwaves.[169] In 1957, Townes and Schawlow proposed the extension of the same idea to light (hence the L in LASER); similar ideas were also put forward by Gould,[170] and by Prokhorov in the USSR. The first successful implementation for visible light was achieved in 1960 by Maiman, who is now generally said to be "the father of the laser".

In China, the first laser was built under the leadership of Wang Daheng (1915–2011) at the Changchun Institute of Optics and Fine Mechanics in 1961, only a year after Maiman's invention. Wang, with an undergraduate degree from Tsinghua, gained a Boxer Indemnity Scholarship for further studies in the UK, obtaining a master's degree from Imperial College in 1941 and then going on to Sheffield to pursue a doctorate. According to his own reminiscences (CAST, 2021), he gave up doctoral studies after one year, to join an industrial research lab in the area of glass-making, because he wanted to acquire the industrial know-how (rather than mere book knowledge) that he felt China needed. He returned to China in 1948, well trained in classical optics (i.e., the branch of optics that does not have to worry about individual photons) and was skilled in making optical glass, lenses and coatings. Importantly, in 1952, he founded the Changchun Institute of Optics and Fine Mechanics under CAS, and very quickly built up infrastructure and a pool of expertise. The Institute was, and remains today, a leading centre in China for optics and precision engineering.

There, Wang Daheng's former student Wang Zhijiang made the first Chinese laser (a ruby laser) just a little over a year after Maiman's breakthrough. No doubt the achievement rode on Maiman's ideas, but some aspects of implementation were different. Catching up so quickly was remarkable; more importantly, the Institute was *prepared*. Thus, a series of different lasers followed: He-Ne lasers and Nd-glass lasers in 1963, and GaAs semiconductor lasers in the same year, Ar ion lasers in 1964 and CO_2 lasers in 1965, YAG lasers in 1966. In none of these were Chinese scientists the first in the world. Nevertheless, the capacity had been developed to follow world trends with a very small lag, as a very credible runner-up.

Insulin

The near-absence of high-level basic science has been remarked. There was at least one exception to this statement, so much so that the work is sometimes said to have come close to a Nobel Prize (Cao, 2004).

Insulin is produced in the pancreas, and its deficiency causes diabetes; this has been known since the beginning of the 20th century. By about 1920, insulin had been extracted from the pancreas of dogs, and then cows (the latter called bovine insulin), and injection cures (or at least regulates) diabetes. This work earned the Canadian researchers the Nobel Prize in Medicine or Physiology in 1923.[171] Since extraction from animal pancreas was inefficient, scientists turned

[169] They used microwaves of 24 GHz, or wavelength of about 1.2 cm, some 20,000 times longer than that for visible light.

[170] Many years later, Gould would win lawsuits for some of the relevant patents.

[171] The inventors did not want to benefit financially, and patented the process only to prevent

to the possibility of synthesising insulin, which is just one large molecule (molecular weight about 6,000). Chinese scientists succeeded in 1965. It was a huge project, involving three teams at the Institute of Biochemistry in Shanghai, Beida, and the Shanghai Institute of Organic Chemistry, working together rather than in competition. There was no thought that any individual or unit would profit by the invention, and initially no thought of scientific awards — the idea of highlighting individuals ran counter to the collective spirit of the time.

The Cultural Revolution erupted in 1966 and external links were almost completely severed, so the breakthrough was known abroad only to a small circle of specialists. It was some years later that the national leadership realised that this work was world-class and deserving of international recognition. Only in 1977 was the matter formally raised in CAS, and in the next year approval was given, supposedly by Deng Xiaoping himself, to put in a nomination to the Nobel committee — overcoming previous hesitation about giving limelight to individuals.[172] There was a further hurdle: at most three persons could be nominated, while the insulin project in China had four recognised leaders. It was in the end decided to put up only one candidate, Niu Jingyi, in part because arguably contributions had also been made by European scientists (see below), with whom the prize might have to be shared. Although the nomination did not succeed, there is agreement that a Nobel Prize would not have been out of place.

Apart from early indecision to go for a nomination, the limited international exposure (i.e., "marketing") during the decade of Cultural Revolution, and probably lack of experience in writing up the nomination, there was in fact another reason that is often glossed over.[173] The Chinese team was not the first to synthesise insulin (as is often erroneously claimed), but the first to synthesise a form of insulin *with good biological activity*; the earlier European work is reviewed by Katsoyannis (1966).[174] The biological activities depended on the synthetic routes adopted, which produced different three-dimensional structures (and also different levels of purity).[175] In those days, not much was known about three-dimensional structures, so the synthetic outcomes were not planned; they were somewhat accidental, or in the case of the Chinese team, results of patient trial-and-error (Xu, 2015). That might be one reason why

others from claiming priority; they then "sold" the intellectual property to the University of Toronto for one dollar, with the stipulation that it should be deployed in a non-profit manner. Such ethical behaviour was exceptional in the Western world in those days, and would be regarded as nearly lunatic now — for implicitly undermining the very foundation of capitalism. However, it would have been the expected behaviour in socialist China, as will be apparent in the story below.

[172]The years 1977–1978 saw the critical turn to a policy of reform and opening up; see the next Section. Before that watershed, international connections were frowned upon.

[173]I am indebted to Prof Xie Zuowei for patiently explaining to me the intricacies. However, the views expressed are mine.

[174]In addition, the European product was based on sheep insulin, while the Chinese product was based on bovine insulin; however, this distinction is purely incidental.

[175]Almost everyone knows by now how the spike in the SARS-CoV-2 virus is critical to its properties.

neither the European scientists nor the Chinese scientists won the Nobel Prize in this instance.

A quick look at the principal scientists in the insulin project will illustrate how a generation of returnees armed with overseas doctorates helped to lead national scientific efforts, passing the torch to the next generation educated domestically, and also how inter-institutional dynamics played out in those days. The acknowledged overall leader was Wang Yinglai (1907–2001), PhD Cambridge 1941, then working at the Institute of Biochemistry. Also there and a fair bit younger were Niu Jingyi (1920–1995), PhD Texas Austin 1953, and Zou Chenglu (1923–2006), PhD Cambridge 1951; both were undergraduates at Southwest Associated University. At the Shanghai Institute of Organic Chemistry was Wang You (1910–1997), PhD Munich 1937. The youngest was Ji Aixue (1933–1993) at Beida, who was trained entirely at Beida itself. Among these five, Wang graciously bowed out, saying that he was only the administrative leader. The other two units deferred to the Institute of Biochemistry to nominate one candidate, and in the end Niu was put forward.

The European teams were relatively small. So why was the Chinese project seen as a herculean effort? First, some of the necessary reagents were not available in China, and had to be produced in-house. Second, the scale of the Chinese teams meant that many different recipes could be tried to find the most effective product. This last remark illustrates how practical success hinged on the collective system, even when it is not necessarily positive for revolutionary innovations, and downright inconvenient as far as individual-based prizes are concerned — an issue that appeared also in the case of Tu Youyou.

Chinese medicine and Tu Youyou

Tu Youyou (born 1930) won the Nobel Prize in Physiology or Medicine in 2015, "for her discoveries concerning a novel therapy against Malaria" (Nobel Foundation, 2015). Although the award is relatively recent, the discovery was made in the early 1970s, so belongs to this segment of our story.

The award citation is not strictly correct: the therapy was quite the opposite of "novel"; her achievement relates to an *ancient* therapy in traditional Chinese medicine. She was educated entirely in China (at Bejing Medical University, now part of Beida), and her research was also carried out entirely in China (at the China Academy of Traditional Chinese Medicine).

Malaria is a debilitating tropical disease. For a long time, the therapeutic agent of choice was quinine and its derivatives.[176] However, quinine is not very effective and in large doses has undesirable side effects. Thus, around 1967, North Vietnam appealed to China for help in seeking possible cures. For context, recall that North Vietnam was at war with the US, with soldiers often trekking through mosquito-infested jungles. In China, the Cultural Revolution was wrecking academic and research organisations, but a project responding to

[176]Interestingly, quinine is also extracted from plants, in this case the bark of a certain tree. The characteristic taste of tonic water (originally designed to prevent malaria, now used often in gin-and-tonic) is due to a tiny quantity of quinine.

a call by national leaders was largely immune to the troubles, and moreover, seeking a cure from traditional Chinese medicine was very much in line with the peasant-inspired values being promoted at the time.

Scientists scoured through tens of thousands of candidate compounds. Chinese scientists had the advantage of ancestral wisdom, and narrowed the search to the traditional Chinese pharmacopoeia, for formulations described as effective against symptoms similar to malaria. Hundreds of recipes were tried, chemicals were extracted and trials performed on mice. Wormwood was apparently effective, but initial attempts to extract the active ingredient failed. At this point Tu made an important contribution: she noticed an ancient text that prescribed the herbs to be soaked overnight in cold water, rather than boiled; she therefore suspected that perhaps the active ingredient cannot withstand heat. She then tried a cold extraction route — which succeeded. The active ingredient artemisinin (generally known in Chinese as *qinghaosu*) together with its derivatives, is now the principal drug for treating malaria. Tu's team also determined the chemical structure of artemisinin, and Tu herself was the first volunteer in the safety trials.

The Nobel Prize of 2015 was fitting tribute for this work, and for the entire enterprise of Traditional Chinese Medicine (TCM) and especially its modernisation. It also gave recognition to research carried out entirely within China, and was also a boost to women scientists. Surprisingly, Tu was never elected to the Chinese Academy of Sciences. The reasons are still somewhat obscure. One lame excuse is that she is past the normal age for election to the Academy, but she was just over 40 when the key discovery was made. The strong-willed lady probably rubbed some people the wrong way. There might also have been some feeling among peers that the achievement was more a group effort than a uniquely personal triumph. After all, it was a top-down national project, with a division of labour as to who would work on which candidate herbs; most candidates failed, and Tu happened to get her hands on the one that worked. No doubt there is some element of truth in such an assessment, but it is equally true that wormwood would have slipped through the fingers of a less talented scientist, for example, if cold extraction had not been tried. Be that as it may, the nation made up for the omission[177] with very high-level awards: the Highest Science and Technology Award in 2016 and the even more prestigious Medal of the Republic in 2019.[178]

It is interesting to note, parenthetically, that in 2021 there have been suggestions in peer-reviewed articles that artemisinin may have applications in combating COVID-19; see, e.g., Fuzimoto (2021).

[177] Election to the Academy, for all the faults that one can find, is a truly democratic process, and the State is unable to control the outcome.

[178] Winners of the Highest Science and Technology Award number fewer than 20. Only nine people have been awarded the Medal of the Republic, including Yu Min mentioned above in relation to nuclear bombs, Yuan Longping for hybrid rice, and Zhong Nanshan well known to us in Hong Kong through his contributions in the SARS and COVID epidemics.

12 Science and technology in the age of reform

Context: a watershed

Political changes

The first three decades of the PRC and the subsequent age of reform are fundamentally different, not only for science and technology, but for all of society. This distinction, in particular the sharp divide between the decade of the Cultural Revolution (1966–1976) and the forty-some years since, is the one fact that must be grasped by anyone coming for the first time to contemporary Chinese history. With apologies to Dickens, it was "the worst of times" and it is "the best of times":[179]

> It was the best of times, it was the worst of times, it was the age of wisdom, it was the age of foolishness, it was the epoch of belief, it was the epoch of incredulity, it was the season of Light, it was the season of Darkness, it was the spring of hope, it was the winter of despair, ...
>
> (Dickens, 1859)

Despair and darkness aptly describe the Cultural Revolution; hope and light characterise the decades that followed.

In September 1976, Mao died. The radical wing, especially the Gang of Four,[180] were poised to take power and would no doubt have continued the excesses of the Cultural Revolution. Fortunately for the nation, a coup was staged in October, led by Marshal Ye Jianying with the support of the moderate and rational veterans (of whom only a small number were clinging to office after a series of purges during the Cultural Revolution, and with Zhou Enlai and Zhu De having died in the preceding months), and with the agreement of Hua Guofeng, Mao's anointed heir. The Gang of Four were arrested, to cheers across the country when the news broke.

The political transition was formalised at the Third Plenum of the 10th Central Committee held in July 1977.[181] Deng Xiaoping had his posts restored, but Hua Guofeng was in charge, though without a strong political base. Hua's cooperation was instrumental in toppling the Gang of Four, but he was nevertheless a political conservative with a limited vision. He is infamously associated with the "Two Whatevers":[182]

[179] Dickens referred to one single period in time; here, with literary licence, we refer to two different periods.

[180] Wang Hongwen, Zhang Chunqiao, Jiang Qing (Mao's wife), Yao Wenyuan — listed in the order in which they came to be cited when they were denounced in 1977. All were members of the Politburo; Zhang and Wang were on the Standing Committee.

[181] The Central Committee of the CPC, consisting of about 200 members, is elected by the National Congress of the CPC typically very five years. The 10th Central Committee had been elected in 1973, and its previous plenary meeting was in 1975.

[182] The statement first appeared in February 1977, simultaneously in *People's Daily*, *Red Flag* and the *PLA Daily*, obviously with approval from the very top. The statement probably did not originate with Hua, but he certainly went along with it, and on various occasions made public statements in the same vein.

> Whatever Chairman Mao decided, we shall resolutely defend. Whatever Chairman Mao directs, we shall unwaveringly follow.
>
> (*People's Daily*, 1977)

The 11th Central Committee was quickly constituted, and held its first Plenum in August 1977. By that time, Deng was officially number three in the Party, listed after Hua and Marshal Ye. His influence was growing: he gave the closing speech, which, though short on specifics, set the tone of change. Significant policies were announced at the Third Plenum held in August 1978. For the first time, modernisation (rather than revolution or class struggle) was placed high on the agenda (CPC CC, 1978, Sect. 1); economic development and technology innovation were given attention; the Four Modernisations[183] were cited (in the order agriculture, industry, defence, and science and technology). Very importantly for our discussion, the Plenum affirmed the principle that "practice is the only criterion to judge truth" (CPC CC, 1978, Sect. 4). The point of view was first put forward a few months earlier by a philosophy professor, was vetted and approved by Hu Yaobang,[184] and was published in *Guangming Daily* — obviously meant to negate the "Two Whatevers".

One might say that the point was merely philosophical; nevertheless there were enormous consequences. In a sense, it was a much delayed and compressed version of the same debate and the same transition that had heralded the advent of the modern age in Europe. The medieval standard was "Whatever the Bible says is the truth", a point of view which stood in the way of scientists (and would-be scientists) all the way to Galileo (c. 1615). Only when the "Whatever" was given up could modern science arise in Europe, with the growth of empiricism (e.g., Bacon, c. 1620), rationalism (e.g., Descartes, c. 1640) and finally the Enlightenment call: "Dare to know! Have the courage to use your own intelligence!" (Kant, 1784).

The change in the political landscape impacted science in at least three ways. (1) There was immediately a sense of liberation and purpose among scientists. (2) The slow task of rebuilding academic institutions began. (3) The resultant gains in the economy over the next decades drove a virtuous cycle with steady improvements in education and in science and technology.

Rebuilding institutions

Universities had been devastated during the Cultural Revolution. Many professors were humiliated. Scholars as well as students were sent down to the countryside to be re-educated. The scholars had gradually started to return in the later years of the Cultural Revolution; the flow accelerated with the change of national policy, and universities as well as research institutes were re-staffed. A crucial event was the re-establishment of a nation-wide examination system

[183] The term had in fact been used in the early 1960s, but became an important rallying call only from 1978.

[184] Then head of the Organisation Department, later to become the General Secretary of CPC.

(now *gaokao*) for selecting students to higher-education institutes — in the years of the Cultural Revolution, selection had been based on recommendations from villages, factories and work units, often emphasising perceived political correctness. The first examination under the new system, held towards the end of 1977, was met with enthusiasm among the most capable young people. The initial cohorts were of specially high quality, filling a relatively small quota from the pent-up demand of a whole decade.[185] However, for some ten to fifteen years, funding was scarce, facilities were inadequate, and contact with the outside was limited.

The Spring of Science

In March 1978, at the closing of the Science Congress, Guo Moruo,[186] President of CAS, made a famous speech entitled "The Spring of Science", which captured the positive mood among scientists at that time.

> The Chinese people have made outstanding contributions in the history of human civilisation. ... [Now] we need not only giants in politics and culture, but also giants in natural science and in other domains.
>
> (Guo, 1978)

An iconic event

A small and iconic event would serve to illustrate the changes during the transition. The Guangzhou Conference on Particle Physics was held in January 1980, in fact not in Guangzhou but in Conghua, a town in the foothills some 70 km northeast of the provincial capital, famous for its hot springs. Particle physics studies the basic constituents of matter and their mutual interactions, and is regarded as one of the most exciting frontiers of science. Why would a mere academic conference merit discussion? Nowadays such conferences are routine, organised regularly by university departments or learned societies. But the Guangzhou Conference was the first one of any significant scale held on the mainland to which participants from around the world were invited. The language of the conference was a mixture of Chinese and English, so only ethnic Chinese were invited. The event was such a departure from past practice that it had to be initiated by a consortium of four parties: the Chinese Academy of Sciences (CAS), the Ministry of Education (MOE), the Foreign Ministry and the Hong Kong and Macao Office (the last two because scientists from other

[185] Thus, students of those few cohorts spanned a fairly large difference in age. They were not only academically excellent, but must have been also the most resilient, often having studied on their own under difficult circumstances.

[186] Guo, better known as a man of letters, was a scientist only by a liberal interpretation of the term: the closest he came to science as now conventionally defined was through his interest and expertise about ancient texts — which bordered on the science of archaeology. He has at best a mixed reputation, being often regarded as spineless during the Mao years. Nevertheless, the scientific community thought highly of this particular speech.

countries and also from Hong Kong were invited), and had to be approved by the State Council. A vice governor of the province[187] was present throughout the week-long meeting, to ensure provisions in those days of rationing and food coupons. Upon the conclusion of the conference, participants were invited to Beijing, and to a banquet hosted by Premier Hua Guofeng and Vice Premier Deng Xiaoping.

On the scientific side, the Chairman of the Conference was Zhou Peiyuan (1902–1993, PhD Caltech 1928), at that time President of Beida and also President of the Chinese Physical Society. The stars were TD Lee (Columbia University) and CN Yang (State University of New York at Stonybrook), co-winners of the Nobel Prize in 1957. Lee and Yang were both students at Southwest Associated University during the war years, and Zhou was a professor there. Many connections of this sort gave the event an atmosphere of a great family reunion.[188]

In retrospect, the standard of the conference was adequate but not high; after all, Chinese scientists had lost a decade or more of contacts with international peers. However, there was a great sense of optimism and purpose, and a strong urge to catch up; middle-aged physicists were possessed with a level of energy more commonly associated with doctoral students. The immediate impact was of course a rapid process of updating to the latest developments. More importantly, friendship with ethnic Chinese scientists abroad was cemented, leading to collaborations and mutual visits in the subsequent years and soon spreading to the wider circle of international scientists. And, of course, this kind of academic conferences with global participation soon became no longer exceptional, across the entire spectrum of science. With contacts developed, the next generation of budding scientists had the opportunity for further studies abroad, starting a trickle that eventually grew to a wave in the 21st century.

Economic development and other indicators

Economic growth

The years following the reform and opening up witnessed a phenomenal rate of economic growth, unequalled in human history (except possibly for small regions or for short periods of time). The comparison with the US shown in Table 4 (and the comparison would be broadly the same for other developed economies) tells the story at a glance: whereas the US economy expanded by a factor of 7 over 40 years, the Chinese economy expanded by a factor of 70! Moreover, the present gap of about 2-to-3 is closing rapidly, and the Chinese GDP is projected to surpass the US GDP within this decade (and in purchasing power parity terms may have already done so) — even though there is still a large gap in per capita terms.

[187] The governor at the time was the father of Xi Jinping.

[188] I had the good fortune to be present, and even had a long chat with Zhou, among other things about our respective times at Caltech 40 years apart.

	China	US
1980 GDP (USD trn)	0.2	2.9
2020 GDP (USD trn)	14.7	20.9
Multiple in 40 years	70	7

Table 4: GDP of China and US in 1980 and 2020, in USD trillion. Data from World Bank (2021a).

The economic expansion went through several overlapping stages. Productive energy was immediately unleashed when the collective economic system was relaxed and then essentially abandoned. Next, low-end industries took off, in many cases relying on the low cost of labour. Industries with more technology content were introduced, initially often with outside partners who brought both capital and know-how, and later with widespread growth of indigenous establishments, so that China is now the "workshop of the world" — a term that was used to describe 19th century Britain (Hudson, 2011). Then proprietary intellectual property propelled new products, launching an economy increasingly driven by innovations. Obviously technology (if not science) played an important role in the later phases. Science and innovation are necessary ingredients for moving up the value chain and avoiding the middle-income trap (ADB, 2017).

The story of the automobile industry, especially for passenger cars, illustrates well the stages in this process. In the early 1980s, China had only a few antiquated automotive works, their output supplemented by Soviet imports also of low quality. Then joint ventures were established, e.g., with American Motor Corporation in Beijing, with VW in Shanghai and with Peugeot in Guangzhou, followed by other brands such as Toyota and Nissan. With key technologies withheld, these joint-ventures were little more than assembly plants. A number of domestic manufacturers emerged, but none was very successful. As a result of growing demand, imports soared, despite heavy duties. More recently, domestic enterprises took advantage of the disruptive electric vehicle (EV) revolution powered by the need to reduce carbon emission.[189] In 2021, Chinese producers SAIC and BYD are respectively third and fourth globally in terms of plug-in EV sales,[190] coming in after Tesla and VW (INSIDEEVS, 2021a). BYD is especially impressive in its integration of artificial intelligence (AI) and a novel battery design, with rumours in the market that Tesla may be buying BYD batteries (INSIDEEVS, 2021b).

The economy intersects with science and technology in other important ways, though the results will take longer to become manifest. There is now the revenue to invest substantially in R&D, so that society enters a virtuous cycle with economic growth and technological advancement propelling each other forward. In the longer term, increasing affluence in society will allow a shift of emphasis,

[189]There should be a health warning in relation to the hype about reduction of CO_2 emission. It is true that the EVs as such do not emit CO_2, but the power plant producing the electrical energy does — and may even cause *more* emission of greenhouse gases if the plant is coal-fired.
[190]Not restricted to passenger cars.

both socially and individually, away from concerns about immediate utility (this generation is probably the first in Chinese history not to worry about the next meal) and towards pursuits driven simply by curiosity about nature, which will in the long run benefit basic science — a point to which we shall return in the next Section.

Scientific productivity

Keeping pace with the size of the economy, quantitative indicators of scientific productivity have also risen sharply, in many cases ranking within the top one or two in terms of total output. Table 5 shows the top few countries for science and technology journal articles published and Table 6 tells a similar story about patents.

China	528
US	423
India	135
Germany	104
Japan	99
UK	98
Russia	82

Table 5: Scientific and technical journal articles published, in 2018, in thousands. Data from World Bank (2021b).

China	1244
US	285
Japan	245
Korea	171
Germany	47
Russia	23
India	19

Table 6: Patent applications in 2019, in thousands. Data from World Bank (2021c).

Such data are on the one hand encouraging, but must on the other hand be read with caution. First, the statistics on a per capita basis is less impressive. Second, there is much more of a bean-counting culture in China (the reasons for which we shall discuss separately), such that scientists have a sometimes perverse incentive to publish or to seek patents whether or not the result is particularly worthwhile or interesting.[191] This observation hints at two challenges for the years to come: (1) emphasis on quality rather than quantity, and (2)

[191] If your grade is pegged to the number of words in your term paper, you will no doubt write at great length, whether or not you have anything to say.

shifting recognition and rewards from bureaucrats (who can only understand hard numbers, or worse yet, only media hype) to independent peers.

Recent achievements in science and technology

The statistics should be given flesh and blood by specific examples of notable recent achievements. In certain fields, China is acknowledged to be world-leading: electronic payments and high-speed trains come to mind — not necessarily that other countries cannot do it, but that they have not done it, perhaps for reasons other than technological capability. In implementation of 5G communication technology, Huawei is certainly a world leader, so much so that there are underhand tactics to destroy the company.[192] In artificial intelligence (AI), China is also regarded as leading (Marr, 2021; Li, Tong & Xiao, 2021). SenseTime, an AI company spun off from CUHK, had its stock listing in Hong Kong in late December 2021 almost sabotaged.[193]

Achievements in space exploration have received wide attention. Possibly the most important (if not the most spectacular) is the Beidou navigation system (three generations in 2000, 2011 and 2015) which now provides an alternative to the US, European and Russian counterparts. Missions to the Moon are named in the Chang'e[194] series (Table 7).

Sequence	Year	
1	2007	orbited Moon
2	2010	orbited Moon
3	2013	landed on Moon
4	2018	landed on backside of Moon
4	2020	landed and returned with 1.7 kg of sample

Table 7: Chinese Moon missions in the Chang'e series.

The first astronaut went into space in 2003.[195] Several missions later, Chinese astronauts are now spending months in a large space station (Tiangong).[196] A probe to Mars was launched in 2020, landing a rover to explore the Martian surface.

[192] However, Huawei was able to announce 76% increase in profit in 2021.

[193] US investors including investment funds are forbidden to take up shares. In the end, the sudden ban caused only a short delay to the IPO. Ironically, the ban was seen as an implicit endorsement of technical superiority, and helped to push the share price up by some 40% one week after the IPO.

[194] Chang'e is the mythological goddess of the Moon.

[195] At least two billionaires with large egos (Bezos and Branson) have orchestrated flights as private enterprise. So one might be led to think that space flights are no longer such big deals. However, such an impression would be the victim of misleading public relations campaigns. These "flights" only put vehicles up beyond the atmosphere and allowed passengers to experience some minutes of weightlessness when the rockets were turned off; the vehicle did *not* orbit the Earth — as all genuine astronauts do.

[196] At the time of writing in December 2021, three astronauts are in Tiangong-2, and are expected to return after a six-month stay.

On another frontier, an unmanned submersible reached a depth of 10,000 m, almost equal to the maximum depth of the oceans and essentially matching the record of several countries, some of which have also deployed manned submersibles (though the scientific advantage of the latter is not obvious).

In civil aviation, the regional jet ARJ21 (capacity of under 100 seats, range about 3,000 km, designed in China but using General Electric engines) has come into domestic service. The larger C919 (about 150 seats, range up to 3,000 km, designed in China and using LEAP engines from a US–French consortium) will be a competitor to Airbus 320 and Boeing 737, thus projecting the Chinese aviation industry into the ABC triumvirate as its junior member.[197] The yet larger C929 (about 300 seats, up to 12,000 km range, either Rolls Royce or General Electric engines) is in design and prototype stage, and should come into use within this decade, competing in the same arena as Airbus A330 and Boeing 787. Many key components rely on external suppliers, though Airbus and Boeing also outsource.

In moving away from fossil fuels, China is dominating in photo-voltaic (PV) production (Buchholz, 2021); has the largest installed wind power capacity of over 350 GW (Unwin & Farmer, 2021), more than double that for the US in second place,[198] and built half the world's wind-farms in 2020 (Ambrose, 2021); and is third in the world in terms of installed nuclear power capacity, after the US and France (Kumar, 2021). Nuclear energy again illustrates the stages of development. The first modern plant is the one at Daya Bay (start of construction 1987, commercial operation 1994); some of our electricity supply in Hong Kong comes from this plant. This pioneering plant was a French reactor.[199] Not only was there a technology gap, but foreign currency was also a problem at the time — thus China Light and Power (CLP) in Hong Kong was brought in, to take up 70% of the output, and, not incidentally, to bring in its management experience. Later installations (e.g., the CPR-1000 version) were Chinese-built reactors with core technology licenced from the French. A further evolution to proprietary technology led to versions (such as the ACP-1000) that could be exported. Now, there are efforts to design novel reactors that are smaller, more efficient and endowed with better intrinsic passive safety features.[200]

The list of achievements can hardly be exhausted, but the above examples should suffice to paint an overall picture of the advances made since the reform and opening up.

Basic science

The reader may be struck by the dearth of examples drawn from basic science, or at least science rather than technology. First, it is necessary to remark that the

[197] ABC has come to mean Airbus, Boeing and Comac (Commercial Aircraft Corporation of China).

[198] A typical coal-fired or nuclear power plant is about 1 GW or less.

[199] But the second stage where the reactor thermal output drives a conventional steam turbine is British — not that the French could not have built it all in one go, but before 1997, CLP in Hong Kong was subject to arm-twisting by the UK government.

[200] Namely, shutdowns relying on physics rather than engineering or operator intervention.

tilt towards technology (rather than science) does not originate from a bias in my choice of examples; most Chinese commentators on science and technology, including official media and state leaders, would point to a largely similar list — thus reflecting not only the balance of achievements, but also the balance of what is *regarded* as important. Second, if one looks at achievements in basic science at very high levels, it is unfortunately true that very few can be found.

To make this statement somewhat objective and to avoid any bias, especially self-congratulatory wishful thinking, a selection will be made based on winners of major international prizes.[201] There is of course Tu Youyou's Nobel Prize in 2015, but that work was done in the 1970s. If one considers discoveries in this century, only two works done in China have been associated with these major prizes: the transmutation of neutrinos and DNA in blood plasma, winning the Breakthrough Prize respectively in 2016 and 2021. For the former, China had roughly a half share, within which CUHK contributed a part; the latter is entirely a CUHK project, still going towards further impacts. While one should celebrate these achievements (and CUHK's role in them),[202] one must at the same time lament that *there is nothing else that can be cited.*

Neutrino transmutations

(I thank Prof MC Chu for commenting on a draft of this part.)

Neutrinos are elusive particles that hardly interact, and are therefore difficult to detect. They were first proposed by Pauli in 1930 as an undetected particle to explain the missing energy and momentum in β decays.[203] The first variety ν_e was found in 1956,[204] a second variety ν_μ was discovered in 1962 and a third variety ν_τ (by that time expected) was discovered in 2000. Nobel Prizes were awarded for the first two discoveries.[205]

Neutrinos (ν_e) are also produced as a byproduct of the fusion process which powers the Sun. The ratio of neutrinos to the energy production can be predicted by known nuclear physics and reliable solar models, but the flux when measured on Earth was only half of what was expected.[206] Eventually the ac-

[201] Of course one starts with the Nobel Prizes in science (about USD 1 million). Then there are the Breakthrough Prizes (up to USD 3 million, but often shared across several teams, each of which may also be large). The Shaw Prize (USD 1.2 million) is awarded in astronomy, life science & medicine, and mathematical sciences. The Kavli Prize (USD 1 million) is awarded in astrophysics, nanoscience and neural science. The Abel Prize (about USD 0.8 milion) is awarded in mathematics. The following smaller prizes are not included. The Lasker Awards in medical sciences is prestigious, but quite a bit smaller (USD 0.25 million). The Fields Medal is limited to young mathematicians and carries a modest sum (about USD 15,000).

[202] No effort is made to deliberately highlight our own university; the selection is objectively based on the list of major prizes.

[203] Actually in β decay, an *anti*-neutrino is emitted, but we shall gloss over this distinction in this account.

[204] Based on a method first suggested by Wang Ganchang more than a decade earlier, before he returned to China. See Table 3

[205] There is a famous saying by Fermi that "Experimental confirmation of a prediction is merely a measurement."

[206] The other half of Fermi's saying is "An experiment disproving a prediction is a discovery."

cepted explanation is that one variety of neutrinos can transmute into another, and about half of the ν_e had turned into other varieties on its way from the Sun; the detector is sensitive only to the original variety ν_e. The rates of transmutation are determined by three parameters called mixing angles. The two larger ones θ_{23} and θ_{12} were quickly measured. The Daya Bay experiment was designed to determine the last small one θ_{13}.

As with all high energy experiments,[207] hundreds of scientists were involved, from many institutions across many countries. The two major teams were respectively from China, led by Wang Yifang of the Institute of High Energy Physics and from the US, led by KB Luk[208] of the University of California at Berkeley; they were the two named recipients of the Breakthrough Prize. Other members of the team included MC Chu and his experimental group at the CUHK Physics Department.

The idea is that nuclear fission in reactors produces a flux of (anti-)neutrinos. Detectors are set up at different distances, and if the measured flux departs from an inverse-square relationship with distance, that would be evidence of transmutation into other forms. The Daya Bay experiment, despite a later start, had several advantages over French competitors, including the following. (1) At Daya Bay, there were six reactors in a cluster (versus only two in the French case), so there was a stronger beam of neutrinos to start with. (2) The Daya Bay detectors were much larger, giving rise to a proportionately larger number of events. (3) There happens to be a small hill nearby (versus flat country for the French), so that when instruments were placed in a tunnel dug into the hill, the overlay of rocks filtered away most of the cosmic rays, removing the "noise" that would confound the signal.[209] In the end, the Daya Bay experiment was the first to report accurate results (An et al., 2012, 2013), and, as already mentioned, won the Breakthrough Prize a few years later.

One might be tempted to ask: What is the practical use of this discovery? The short answer must be "none" — though there could be long-term spin-offs from the technology developed from the needs of the experiment; it is perhaps not widely known that the World Wide Web grew out of the need to share data across continents in such high-energy experiments. However, such applications are byproducts; scientists are driven simply by curiosity about nature: in this case how elementary particles interact and whether these elusive particles play a significant role in the evolution of the universe.[210]

In this connection it is worth citing a well-known episode in the US, also about high-energy physics. In 1969, Wilson was among a group of scientists testifying before a Congressional committee to seek funding for a new accelerator. One senator asked whether the project would benefit "the security of

[207] This is the term conventionally applied to this branch of experimental physics, though in the case of solar or reactor neutrinos, the energy is actually quite low.

[208] KB Luk was originally from Hong Kong.

[209] Other differences are glossed over.

[210] Neutrinos, especially since the transmutation implies that they must have some mass, are certainly a part of the dark matter that is important in the evolution of structure in the universe, including the formation of galaxies and ultimately the emergence of life.

the country". Wilson answered "no", and the senator was obviously not satisfied. The further answer by Wilson has become famous as a celebration of basic science:

> It has only to do with the respect with which we regard one another, the dignity of man, our love of culture. It has to do with: Are we good painters, good sculptors, great poets? I mean all the things we really venerate in our country and are patriotic about. It has nothing to do directly with defending our country except to make it worth defending.
>
> (Wilson, 1969, in Congressional testimony, as reported in *APS News*, 2018)

DNA in blood plasma

(I thank Prof Dennis Lo for commenting on a draft of this part.)

We all "know" two "facts": (1) DNA resides *inside* cells, and (2) the blood circulations of a foetus and its mother are separated by the placenta and do not mix (the two can have different blood types). Dennis Lo of the CUHK Faculty of Medicine showed that neither of these textbook statements is strictly true. As a result, traces of foetal DNA[211] leak from the cells into the foetal bloodstream, and across the placenta into the maternal bloodstream. This phenomenon was first confirmed in a clever and relatively simple experiment: a tiny amount of XY chromosomes (characteristic of males) was found in the blood of pregnant women who eventually gave birth to boys, but not in those who gave birth to girls.

As a result of these fundamental discoveries, one can now do genetic testing on the foetus by just drawing a small quantity of blood from the mother, without invasive procedures (Lo et al., 2010);[212] the obvious application is testing for Down's syndrome in early pregnancy. This test is now offered routinely by the Hospital Authority in Hong Kong, and is used worldwide under licence authorized by CUHK. For this work, Dennis Lo was awarded the Breakthrough Prize in 2021.

The next stage of the investigations promises to be even more important. If one thinks of the foetus as a "foreign" object whose presence can be detected by the leakage of DNA into the bloodstream, might not the same be true for other foreign objects such as malignant tumours? Lo and collaborators were able to confirm the following (Lam et al., 2018): in patients treated for nasopharyngeal cancer, those with detectable levels of tumour-related DNA fragments in blood are prone to relapse (and should therefore be given further aggressive treatment such as chemotherapy), even when no remaining tumour can be detected by conventional means such as X-rays. The novel test is much more sensitive

[211] In fact, also RNA, but both of the applications cited below rely mainly on DNA.

[212] Otherwise the standard test would involve amniocentesis: inserting a needle into the mother's abdomen to extract some fluid from the womb, a procedure that carries some risk of harming the foetus.

because it operates at molecular rather than macroscopic level, and promises to reduce fatalities not only for relapse, but also for screening of high-risk groups. Early diagnosis through cell-free nucleic acid is already offered commercially.

An overview of these developments can be found in Lo et al. (2021).

13 Looking to the future

As the third decade of the century unfolds, one sees a strong advance in technology and applications, increasingly powered by innovations in addition to replication and refinements of existing products and processes. The technological advance has a positive impact on the economy, and is a critical component of the strategy to achieve a modest level of prosperity (*xiaokang*) and to rejuvenate the fortunes of the nation (*fuxing*). Yet, despite isolated achievements, there is less to boast about in basic science; any objective comparison at the highest levels would place China behind much smaller nations such as UK, Germany and Japan.

Given this uneven landscape, what can one say about the future? It is well to first examine the official strategy and plans. The pivotal role of innovation has been apparent for some years now.

> Innovation is the primary force driving development, and it is the strategic underpinning for building a modernised economy.
>
> (Xi Jinping at the 19th National Congress of CPC, October 2017, as cited in Tse, 2019)

The 14th Five Year Plan

More detail can be found in the Five Year Plans, which, despite the move to a market economy, continue to be the blueprint for national development. The "The 14th Five Year Plan and Vision for 2035" (NDRC, 2021) sets out the goals for 2021–25 and beyond.[213] The first three Parts of the Plan are organised as follows; the Arabic numerals indicate chapter numbers.

> **I: Introduction**: (1) Context, (2) Principles, (3) Goals.
>
> **II: Innovation as driving force**: (4) Science & technology strength, (5) Innovation capacity, (6) Innovation personnel, (7) Science & technology and innovation system.
>
> **III: Modern industries and the real economy**: (8) Manufacturing, (9) New industries, (10) Service industries, (11) Modern infrastructure.

The document goes on to a total of 65 chapters, but the first few chapter headings already reveal the thrust of national strategy: Innovation occupies pride of place, and the real economy takes precedence over financial markets; class

[213]The English version cited below is my translation.

struggle and revolution are nowhere to be seen. The nation has also come a long way from the call of the Four Modernisations, in which agriculture came first while science and technology came last.

In the specific domain of manufacturing, there is a ten-year vision statement "Made in China 2025" (State Council, 2015).[214] The vision is grand; but the goals, especially the timetable, are realistic, indeed modest. Phase 1 calls for "entry to the ranks of the leading manufacturing nations" by 2025. Phase 2 goals for 2035 include "reaching average levels among the leading manufacturing nations" as well as "significant enhancements in innovative ability, major breakthroughs in key areas, obvious improvements in competitiveness, global leadership in selected areas of excellence, comprehensive industrialisation". Phase 3 goals set for the centenary of the Republic (2049) include "consolidated position as a major manufacturing nation, comprehensive capabilities on a par with the leading manufacturing nations of the world, leadership in innovation capacity and manifest edge in the principal manufacturing domains, established globally leading technology and production system".

Ten domains are highlighted: novel information industry, high-end digital machine tools and robots, aviation and aeronautics, marine engineering, advanced rail transport, energy conservation and automobiles based on novel energy sources, electricity production, agricultural machines and equipment, new materials, bio-medicine and advanced medical equipment.

The key agenda to enhance technological self-sufficiency is regarded as unacceptable by the US (Dezan Shira & Associates, 2018), which deliberately conflates self-sufficiency with ring-fencing the market. Chinese official sources seem to have dialed down the rhetoric, but certainly not the resolve; if anything, technological strangleholds (e.g., UV lithographic equipment for chip-making) are now seen as national threats that must be dealt with, however much resource it takes.

Two contrasting narratives

It is useful to also consider the views of knowledgeable members of the public. Two narratives are deliberately chosen for contrast.

An optimistic assessment

As an example of a rosy view, I choose Edward Tse, founder and CEO of Gao Feng Advisory Company in Shanghai, and author of the books *The China Strategy* (Tse, 2010) and *China's Disruptors* (Tse, 2015). Brief summaries are available through book reviews (Strategy&, n.d.; Pilling, 2015). The short account below draws on a slightly later report (Tse, 2019).

Tse grew up in Hong Kong, went to the US for college in the 1970s,[215] and gained a first degree and then a master's degree from MIT, and then a PhD

[214] All the quotes below are my somewhat loose translations from this document.

[215] With a scholarship from CW Chu, which gives him some connection to the CUHK college of the same name.

from UC Berkeley; he worked for Boston Consulting Group, rising to Managing Partner for China before founding his own company. At least until the pandemic struck, he would commute weekly between Shanghai and Hong Kong. This short biography is meant not only to establish his credentials, but also to label him as a semi-"outsider".

Tse (2019) notes the substantial investment in R&D, now second in the world. At the level of individual companies, Huawei, Alibaba and Tencent are among the global top 100 in terms of R&D spending.[216] The R&D investment has produced copious innovations in areas such as fintech and AI. With some prescience in 2019, Tse cited the CUHK spinoff SenseTime as an example.

A number of factors that support innovations are cited. (1) A sense of opportunity and well-recognised success stories have engendered a sense of "Why not me?". (2) The large state-owned enterprises (SOEs) are slow to react to changing circumstances, leaving opportunities for entrepreneurs. (3) As the planned economy gives way to a market economy, new areas being opened up are not crowded with traditional players.[217] (4) There are "pain points": key problems that need to be solved in the economic transformation; people are willing to pay for novel solutions, often driven by technology. (5) The internet is now ubiquitous, so applications that ride on this platform have a low entry barrier. (6) The huge domestic market is especially important for innovative enterprises, which can amortise their relatively large R&D costs over a wide customer case. The prospect of a large market creates incentives for investors. (7) The large societal saving rate provides capital. The intermediary institutions (venture capitalists) are also positive because they have benefited from the rapid growth of the economy.

Tse puts forward a model of "three-layered duality" unique to China: the central government sets overall policy and goals (e.g., as in the Five Year Plans); local governments leverage on resources at their disposal to exploit opportunities; private-sector entrepreneurs are then able to prosper in this environment. An example will illustrate the point. There is national policy to push AI; Shenzhen is very innovation-friendly and invests in related fields; thus SenseTime and many other companies of the same genre choose to locate there,[218] and are able to grow on a fast track.

The private sector is increasingly important. Tse (2019), quoting an article in the *South China Morning Post*, refers to "56789": that the private economy is responsible for "50% of tax revenue, 60% of gross domestic product, 70% of industrial upgrades and innovation, 80% of total employment and 90% of the total number of enterprises". At the same time, the public sector takes care of infrastructure, including higher education and general R&D.

Paradoxically, the trade war also helps. First (and this is less talked about) China has actually opened up more sectors to foreign companies, removing the

[216] Since then, Huawei has been subject to sanctions from the US, and Alibaba subject to anti-monopolistic crackdown from Chinese regulators.

[217] For example, mobile communication did not have to compete with land lines; e-payments won ready acceptance because most people never had cheque books.

[218] In the case of SenseTime, also in the Hong Kong Science Park next door to CUHK.

protective environment that has been a huge disincentive to innovate. Second, the need to build up domestic technological capability in key sectors (e.g., silicon chips) has become apparent in the face of sanctions.

A cautious view

Of the more cautious (even slightly negative) views one can choose Liu Yadong and in particular a speech given at the 2018 World Science, Technology and Innovation Forum in Beijing (Liu, 2018).[219]

Liu is a veteran reporter with a special interest in science and technology; he studied engineering at Tsinghua, and gained a doctorate in law from Beida. For many years he was the chief editor of *Science and Technology Daily* (*Keji Ribao*). In the 1990s he was posted to New York as the *Daily*'s chief correspondent at the UN. During his sojourn in the US, he acquired an appreciation of the culture of science in that country. After leaving the *Daily*, he joined Nankai University as Dean of the School of Journalism. *Science and Technology Daily* is very much an official newspaper: it was established in 1986 under the auspices of the State Scientific and Technological Commission (SSTC), the State Defence Technology Commission (SDTC), the Chinese Academy of Sciences and the China Association for Science and Technology.[220] Thus, Liu is very much an "insider", which lends credibility to his cautionary remarks.

Liu starts by recalling how "the call for science has been echoing on the ancient land of China". He stresses that science does not just mean scientific knowledge, but more importantly the scientific method and the scientific spirit. He then laments: "In my view, China in 1919 lacked the scientific spirit, and China in 2019 still lacks the scientific spirit", and attributes many societal problems to this gap. He has harsh words about the "low level of original innovation" and the weak basic research, with "few significant theoretical breakthroughs or original pioneering achievements worth a mention", attributing all these ills to "the absence of the scientific spirit". He points to the multiple dimensions of the scientific spirit: "the pursuit of truth, pragmatism, critical thinking and scepticism, perseverance in exploration, courage in innovation, being open to different points of view, and acceptance of failure" — obviously implying that few of these attributes are robust in China.

He points out that the Chinese term *keji* conflates science and technology, misleading the public as well as policy makers. He emphasises the importance of (basic) science in its own right, in a statement that obviously echoes the testimony of Wilson quoted earlier:

> The purpose of scientific research is to discover the secrets of nature and to disclose its principles, and the purpose is not to increase productivity.

[219] The speech was given in Chinese. The quotes below are from a translation by a CUHK undergraduate in 2019.

[220] Since then, SSTC has morphed into the Ministry of Science and Technology (MOST) and SDTC has also been supplanted by different Ministries.

> ... People nowadays should transcend the shallow understanding of science based on mere utility. What can science do? It can enhance the all-round development of human beings and push forward human civilisation as a whole.
>
> (Liu, 2018)

He concludes with a plea:

> The promotion of scientific spirit is ... a necessary ingredient in every aspect of our country: the economy, politics, society, culture and the establishment of an ecological culture. Therefore, only under the guidance of the scientific spirit will innovation activities be dynamic and imbued with hope. ... And I hope that these goals also represent the collective will of our country and the consensus of our society.
>
> (Liu, 2018)

We should recall that Ren Hongjun over a century ago had already spoken about the lack of the scientific spirit (Section 10).

Possible reconciliation

There appears to be a conflict between the two points of view. If one looks at the process from the beginning of an idea to something on the market, there are at least five stages: science, engineering, product R&D, production, and sales. Liu points to weaknesses in the first (and perhaps also a bit of the second) step; Tse points to strengths and successes in the last three — there need not be a contradiction, and they are probably both right. The juxtaposition of both perspectives is perhaps the fairest assessment of the current scene, and a useful pointer for thinking about the future.

The need to bolster basic science is not unrecognised in official quarters — at least at the level of rhetoric. For example, in October 2020 the Minister of Science and Technology spoke about the plan to "expand support of basic research, ... unfashionable subjects, basic and interdisciplinary subjects" (China Net, 2020). It remains to be seen how the wish will play out in practice, in the face of fairly strong currents flowing the other way.

Division of labour

By dividing the process of innovation into these stages, one is naturally led to ask: In which institutions should each stage be carried out? There is no question that basic science and a part of engineering should be carried out in universities and public-sector research institutes, and that production and sales have their homes in private-sector enterprises. However, there is often a strong pressure for universities and research institutes to move "downstream", to take on projects aimed at solving immediate problems of production, or to be rewarded (e.g., with national, provincial or ministerial awards) for having done so. When such incentives go too far, the only institutions (and the only experts) who should

be working on basic research with a long-term perspective are steered off their intended path. Thus it was refreshing to read that Ren Zhengfei, the founder of Huawei, in speaking to the leaders of the C9 universities[221] in November 2020 urged them not to bother with the stranglehold of optical lithography equipment — "leave that to us" (Ren, 2020).

Reasons for weakness in basic science

Possibly the single most important issue for the long-term future of science and technology in China is to understand the reasons for weakness in basic science — and to seek remedies. To the extent that this issue also relates to the scientific spirit, there are also ramifications that go beyond the scientific community, with potential impacts on society at large. There is of not a unique reason, or a definitive and exhaustive list that all commentators agree on. But a number of factors come to mind.

There is the Confucian tradition (whether or not all this can be attributed to Confucius himself): a possibly excessive respect for authority and the ways of old,[222] and (less often remarked) an overwhelming concern with ethics and society that marginalises interest in nature. The Daoist fondness for vague correlative reasoning and disinterest in precision cannot escape a degree of responsibility. Hu Shih (1919) famously caricatured this attitude in the satirical essay "Mr Almost-the-Same".

The pragmatic attitude prevalent throughout society has been remarked by many commentators; see for example the view attributed to Feng Youlan and cited in Section 5. Thus, there has traditionally been little inclination to ask "why", so long as some method or process works. In a sense, one cannot fault the focus on practical results when survival was not assured — as already remarked, it is only in the last few decades that Chinese society as a whole has been able to set aside its worries about hunger. To spend time and effort on questions purely for the sake of curiosity about nature is a luxury that only an affluent society (or an affluent and privileged sector within society) can afford.

The centrally planned economy is on the one hand positive for targeted initiatives, especially large projects that require coordination and commitment of long-term resources, but is on the other hand not friendly towards truly innovative basic science — which by definition explores the unknown and cannot really be "planned". The hierarchical nature of the research community (with bureaucrats at the top) means that working scientists are driven to respond to key performance indicators (KPIs) expressed in hard numbers: the quantity of publications, citations,[223] patents and grants, which, when carried to extremes, surely deter true scholarship.

[221] These are the nine leading universities in China that have formed themselves into a league.

[222] Thus, "innovation" would not be in the vocabulary, much less "disruption" as a term of praise.

[223] There is a preoccupation with the Science Citation Index (SCI). Yang Fujia, formerly President of Fudan and later Chancellor of Nottingham University in the UK, has called the SCI a "Silly Chinese Idea" (Yang, private communication).

Achievements in science necessarily suffer a delay with respect to expenditure in R&D. Lau and Xiong (2022) have argued that scientific output, as measured for example in terms of patent applications and grants in any period, is determined not by the contemporary level of expenditure, but by the *cumulative* investment over a period in the recent past.[224] The economic argument is about science in general, but the conclusion must apply *a fortiori* to basic science. Indeed, there is an element of accumulation beyond the economic dimension. In many examples cited in this lecture, those who have made important contributions had benefited from a good university education in China, which in turn depended on credible departments and centres established by an earlier generation of scholars. To the extent that this factor relating to delayed impact carries weight, one can look to the coming decades with a degree of optimism.

14 Concluding remarks

The purpose of this lecture is to help readers gain some understanding of science and technology in China *today*. But the current situation and the prospect for the future depend on culture and history. It is hoped that this account, from a historical perspective, has helped to shed some light on this important dimension of contemporary China, not just for science and technology *per se*, but also as a window into modern China as a whole.

Appendices

A Convention on Chinese names

The rendering of Chinese names into English is tricky, especially in the choice between (1) standard pinyin and (2) an alternate form that may be common. The convention adopted in this article is explained here.

The default choice is pinyin. However, an alternate form will be used (if necessary with pinyin in parentheses) if that was the version adopted by the person in question, or if that was the name commonly used before pinyin became prevalent. In particular, if the person has published in English, the name of the author as it appears in the publication will be used. Thus we refer to "Yung Wing (Rong Hong)" and "Chiang Kai Shek (Jiang Jieshi)". Commonly adopted Chinese names of some non-Chinese are also given in pinyin, e.g., Li Madou, Li Yuese.

However, in referring to publications in Chinese, the author will be identified by the name in pinyin (because that would appear in a library catalogue), with other conventional forms in parentheses.

[224] Just as a student's performance in an examination is not determined by the effort devoted to study in the preceding week, but could be related to diligence in years past, perhaps even extending to childhood.

Chinese terms whose meaning might be lost in translation are also given in pinyin, in italics as is the norm for non-English words appearing in an English text. Words that have entered the English lexicon are treated as English words. Thus we speak of "Dao" and "Daoism", but "*daojia*" and "*daojiao*". Borderline cases will be judgement calls, e.g., "yin and yang". Proper names are not italicised, unless they appear in a fragment that is italicised for other reasons, e.g., in the title of a book.

Other forms of Romanisation (e.g., Wade–Giles) are converted to pinyin for uniformity.

B The Ho–Leung–Ho–Lee Awards

It is of interest — especially for members of the CUHK community — to mention the Ho–Leung–Ho–Lee (HLHL) Awards for science and technology.

The four names should be familiar to staff and students. The first Ho is Ho Sin Hang, after whom SH Ho College and the Ho Sin Hang Engineering Building are named. Leung Kau Kui Building stands at the corner where Central Avenue turns uphill towards United College, and is home to several departments in the Faculty of Arts. Ho Tim Building, next to the Chung Chi Staff Club, houses the Faculty of Education; there is also the Ho Tim Hall within SH Ho College. The "Pi" in Pi Ch'iu Building is named after Ho Tim's mother. Lee Quo-wei was for a long time Chairman of the CUHK Council, and there is the Lee Quo-wei Hall in SH Ho College. The four gentlemen were linked through their stewardship of Hang Seng Bank through the years; Lee Quo-wei, the youngest of the four, was chairman of the bank for a long time in the 1990s. The four gentlemen and their families have been ardent supporters of CUHK from the inception of the university.

In 1994, the four philanthropists donated HKD 400 million to set up the awards for achievements in science and technology in China. Although the funds are managed in Hong Kong, the awards are operated in partnership with the Ministry of Science and Technology (MOST); the Chair of the Selection Committee has always been a former Minister or Vice-Minister of MOST.[225] One Vice Chair is nominated by the Ministry of Education (usually a serving Vice-Minister) and another Vice Chair is nominated by the donors.[226]

These awards have afforded a front-row seat from which to view some of the most important works and the most prominent scientists in China, and also to gain some understanding on what is regarded as the most note-worthy achievements by the scientific leadership.

Among the scientists whose names appear in this manuscript, the following have won the top-tier Achievement Prize within the HLHL Awards: Qian Xuesen (1994), Wang Ganchang (1994), Wang Daheng (1994), Peng Huanwu (1995), Wang Yinglai (1996), Su Buqing (1998), Zou Chenglu (2003), Zhong

[225] The current chair is Prof Zhu Lilan, a chemist, and former Minister of MOST.
[226] I have served in this capacity for many years.

Nanshan (2020). The second-tier Prize has been awarded to the following:[227] Zou Chenglu (1994), Yuan Longping (1994), Cheng Kaijia (1998), Zhong Nanshan (2003), Wang Yifang (2013).

[227]It can be seen that some of these won the first-tier Prize later.

Bibliography

For resources available in the CUHK Library, call numbers are shown in square brackets. "UL" stands for University Library. "CC", "NA", "UC" stand for the respective college libraries.

Dates are not shown if the year of publication is generally regarded as not specifically known.

Some Chinese names are shown in full, since family name and initial(s) are often not enough to resolve ambiguity.

For publications in Chinese, the name of the author is shown in pinyin, and any alternate form of the name, e.g., conventionally used by the author himself, is given in square brackets. Where the item is in English, the name adopted by the author is used. For names in pinyin such as "Wang Yangming" (rendered without a comma), the first word is the family name and the subsequent word(s) represent the given name.

ADB (2017). Asian Development Bank. "The People's Republic of China in the middle-income trap?"
`https://www.adb.org/publications/prc-middle-income-trap`

Ambrose, J (2021). "China leads world's biggest increase in wind power capacity". *The Guardian*.
`https://www.theguardian.com/business/2021/mar/10/china-leads-world-increase-wind-power-capacity-windfarms`

An FP, et al. (2012). "Observation of electron-antineutrino disappearance at Daya Bay". Phys Rev Lett, 108: 171803.
`DOI:https://doi.org/10.1103/PhysRevLett.108.171803`

An FP, et al. (2013). "Improved measurement of electron antineutrino disappearance at Daya Bay". Chinese Physics C 37, 011001.
`DOI: 10.1088/1674-1137/37/1/011001`

APS News (2018). Vol 27, Number 4. "This month in physics history. April 17, 1969: Robert R Wilson's congressional testimony on founding Fermilab".
`https://www.aps.org/publications/apsnews/201804/history.cfm`

Britannica (2018). Encyclopedia Britannica. "Pythagorean theorem".
`https://www.britannica.com/science/Pythagorean-theorem`

Broadberry S et al. (2015). "British economic growth, 1270–1870", cited in *Our World in Data*. [UL-HC253.B85]

Buchholz K (2021). "China dominates all steps of solar panel production". *Statista*.
`https://www.statista.com/chart/24687/solar-panel-global-market-shares-by-production-steps`

Cao Cong (2004). "Chinese science and the 'Nobel Prize Complex' ". Minerva, Vol 42, 151.

CAST (2021). China Association for Science and Technology. "Wang Daheng: For the motherland, he gave up doctoral studies and went to work as a technician in a glass-making factory" (in Chinese).
scimall.org.cn/article/detail?id=5992860

CEM (2021). The Chinese Educational Mission. *China's First Experiment in Education Abroad, 1872–1881.*
http://www.cemconnections.org/

Chan YC, Pang KM & Young K (2021). "The mathematics of leap years: sophistication versus content in mathematics education". Int J Math Edu in Sc & Technology.
https://doi.org/10.1080/0020739X.2021.1962997

Chang I (1995). *Thread of the Silkworm.* Basic Books, NY. [UL-TL781.85.T836C49]

Chen Duxiu (1919). "A defence against accusations" (in Chinese), *Xin Qingnian* (*New Youth*), Jan 1919.

Chen Fangzheng [Chen FC] (2021). *Jicheng yu Panni: Xiandai Kexue Weihe Chuxian yu Xifang* [*Heritage and Betrayal: A Treatise on the Emergence of Modern Science in Western Civilization*]. SDX Joint Publishing Co., Beijing. [UL-Q125.C4664]

Chen Shou (2007). "The term 'science' in the New Culture Movement and the Science Movement" (in Chinese). Twenty First Century, Vol 104, 58.
http://www1.ics.cuhk.edu.hk/rcccc/21c/index/?author=
&essay=&subject=&issueno=104&property=issueno&direction=ASC&search=1

Chen Wanxiong [Chan Man Hung] (1979). *Xin Wenfa Yundong Qian de Chen Duxiu (1879–1915).* (*Chen Duxiu before the New Culture Movement (1879–1915)* (in Chinese). CU Press. [UL-DS777.15C5C53]

China Net (2020). "Ministry of Science and Technology: During the 13th Five Year Plan the national investment in basic science will increase by an annual rate of 16.9%, and support for unfashionable subjects will also be enhanced" (in Chinese).
http://m.china.com.cn/appdoc/doc_1_3_1771024.html

Chow Tse-tsung (1960). *The May Fourth Movement: Intellectual Revolution in Modern China.* Stanford University Press [UL-DS777.43C55]

City of Zhuhai (2020). "Yung Wing (Rong Hong) (1828–1919): forefather of overseas Chinese students".
http://www.cityofzhuhai.com/2020-11/18/c_270859.htm

CMG (2021). China Merchants Group.
https://www.cmhk.com/en/

Couprie DL (2018). *When the Earth was Flat — Studies in Ancient Greek and Chinese Cosmology*. Springer. Chap. 13, "An ancient Chinese cosmology: main features", pp 263–292.

CPC CC (1978). Communist Party of China, Central Committee. "Communique of the Third Plenum of the 11th Central Committee of the Communist Party of China (approved on 22 December 1978)" (in Chinese).
http://cpc.people.com.cn/GB/64162/64168/64563/65371/4441902.html

CUHK (1983). Twenty-fifth Congregation, Conferment of the Degree of Doctor of Science, *honorìs causa*. "A Citation: Dr Joseph Needham, DSc(Hon), LLD(Hon), DLitt(Hon), PhD(Hon)".
https://cong.cpr.cuhk.edu.hk/hongrads/362

CUHK Humanum. CUHK Research Institute for the Humanities. Multifunction Chinese character database.
http://humanum.arts.cuhk.edu.hk/Lexis/lexi-can/

Daodejing.
https://ctext.org/dao-de-jing

Daxue (*The Great Learning*).
https://ctext.org/liji/da-xue

Dewey J (1921). "New culture in China", *Asia*, XXI, 7, p 642. Cited in Chow (1960) p 456.

Dezan Shira & Associates (2018). China Briefing: "What is 'Made in China 2025' and why has it made the world so nervous?"
https://www.china-briefing.com/news/made-in-china-2025-explained/

Dickens C (1859). *A Tale of Two Cities*. Chapman & Hall, London.

Doyle AC (1892). "Adventure of Silver Blaze", in *The Memoirs of Sherlock Holmes*. George Newnes, London.

Feynman RP (2005). *Perfectly Reasonable Deviations from the Beaten Track: The Letters of Richard P Feynman*, Basic Books.

Fortune (2021). "Global 500: China Merchants Group".
https://fortune.com/company/china-merchants-group/global500

Fu Pu (1982). *Zhongguo Shuxue Fazhan Shi* [*A History of the Development of Mathematics in China*]. Zhongyang Wenwu Gongying She, Taipei. [UL-QA27.C5F8]

Fuzimoto A (2021). "An overview of the anti-SARS-CoV-2 properties of Artemisia annua, its antiviral action, protein-associated mechanisms, and repurposing for COVID-19 treatment". J Integr Med, 19 (5): 375–388. doi: 10.1016/j.joim.2021.07.003

Gongsun Longzi.
https://ctext.org/school-of-names

Goodman AL (2008). "Why didn't science rise in China?". *The New York Review of Books*, 6 November 2008.
https://www.nybooks.com/contributors/alan-l-goodman/

Government of Hong Kong (1860). The Hong Kong Government Gazette, 15 December 1860. "Convention of peace between Her Majesty and the Emperor of China. Signed at Peking, October 24, 1860".
https://webb-site.com/codocs/ConventionOfPeking.pdf

Guo Moruo (1978). "The spring of science".
https://www.pinshiwen.com/cidian/yanjiang/201904087616.html

Hall DL & Ames RT (1998). *Thinking from the Han: Self, Truth, and Transcendence in Chinese and Western Culture*. State University of New York Press. [UC-B126.H255]. Also available online through CUHK Library.

Head A (2018). "Pythagorean Theorem".
http://jwilson.coe.uga.edu/EMT668/EMT668.Student.Folders/HeadAngela/essay1/Pythagorean.html

Hong Wansheng [Horng Wann Sheng] (1999). *Cong Li Yuese Chufa — Shuxue Shi, Kexue Shi Wenji* [*Starting from Joseph Needham: A Collection of Essays on the History of Mathematics and the History of Science*] Jiuzhang Chuban She, Taipei. [UL-QA27.C5H86]

Hu Shih (1919). "Chabuduo Xiansheng Zhuan" ("Mr Almost-the-Same"). See, e.g.,
https://china.usc.edu/sites/default/files/forums/Chabuduo%20Xiansheng.pdf

Hudson P (2011). "The workshop of the world".
https://www.bbc.co.uk/history/british/victorians/workshop_of_the_world_01.shtml

INSIDEEVS (2021a). "World's top 5 EV automotive groups ranked by sales: Q1–Q3 2021".
}https://insideevs.com/news/544766/world-top-oem-sales-2021q1q3/

INSIDEEVS (2021b). "Rumor: BYD to supply Tesla with 10 GWh of LFP batteries".
https://insideevs.com/news/542467/rumor-byd-supply-tesla-batteries/

Kant I (1784). "What Is Enlightenment?" See, e.g.,
http://www.columbia.edu/acis/ets/CCREAD/etscc/kant.html

Katsoyannis PG (1966). "Synthesis of insulin". Science, 154, 1509.
https://www.science.org/doi/10.1126/science.154.3756.1509

Kumar H (2021). "The top ten nuclear energy-producing countries in 2021", Power Technology: Analysis, 23 November 2021.
https://www.power-technology.com/features/
top-ten-nuclear-energy-producing-countries/

Lahanas M (n.d.). "Conic sections: Apollonius and Menaechmus".
http://www.hellenicaworld.com/Greece/Science/en/Conics.html

Lam WKJ, et al. (2018). "Sequencing-based counting and size profiling of plasma Epstein–Barr virus DNA enhance population screening of nasopharyngeal carcinoma". Proc Natl Acad Sci USA, 115(22): E5115–E5124.
https://pubmed.ncbi.nlm.nih.gov/29760067/

Lau L & Xiong Y (2022). *Are There Laws of Innovation?* World Scientific, forthcoming.

Lewis JW & Xue L (1991). *China Builds the Bomb*. Stanford Univ Press. [UL-U263.L49]

Li Yan & Qian Baocong (1998). *Kexue Shi Quanji* [*The Complete Works on History of Science*] (in Chinese), in 10 volumes. Liaoning Jiaoyu Chuban She, Shenyang. [UL-QA27.C5L53]

Li D, Tong TW & Xiao Y (2021). "Is China emerging as the global leader in AI?". Harvard Business Review.
https://hbr.org/2021/02/is-china-emerging-as-the-global-leader-in-ai

Liu Yadong (2018). Speech at the 2018 World Science, Technology and Innovation Forum in Beijing (in Chinese). Translation by Isabel Yang. The original can be obtained from the following sites.
http://finance.sina.com.cn/meeting/2018-08-12/
doc-ihhqtawx1950445.shtml
https://tech.ifeng.com/c/7fMiF1HQFaA

Lo YMD, et al. (2010). "Maternal plasma DNA sequencing reveals the genome-wide genetic and mutational profile of the fetus". Sci Transl Med 2: 61ra91.
https://pubmed.ncbi.nlm.nih.gov/21148127/
doi: 10.1126/scitranslmed.3001720

Lo YMD, et al. (2021). "Epigenetics, fragmentomics, and topology of cell-free DNA in liquid biopsies". Science 372, 144.
https://doi.org/10.1126/science.aaw3616

Lunyu (*The Analects*).
https://ctext.org/analects

Maddison (2018). Maddison Project Databse.
https://www.rug.nl/ggdc/historicaldevelopment/maddison/releases/maddison-project-database-2018

Marr B (2021). "China poised to dominate the artificial intelligence (AI) market". *Forbes*. Enterprise Tech.
small https://www.forbes.com/sites/bernardmarr/2021/03/15/china-poised-to-dominate-the-artificial-intelligence-ai-market/?sh=51b41aa01b38

Mastin L (2010). "Chinese Mathematics", in *The Story of Mathematics*
https://www.storyofmathematics.com/

Martzloff JC (1997). *A History of Chinese Mathematics*, translated by SS Wilson from the French original *Histore des mathematiques chinoises*. Springer, Berlin. Online access through CUHK library:
https://link.springer.com/content/pdf/10.1007\%2F978-3-540-33783-6.pdf

MathWithoutBorders (2012).
https://www.youtube.com/watch?v=_rJdkhlWZVQ

Mote FW (1972). *Intellectual Foundations of China*. Second Edition. McGraw–Hill, New York. [UL-DS721.M73]

Mozi.
https://ctext.org/mohism

NDRC (2021). National Development and Reform Commission. "The People's Republic of China: economic and social development 14th Five Year Plan and the long-term vision and goals for 2035" (in Chinese).
http://www.gov.cn/xinwen/2021-03/13/content_5592681.htm
https://www.ndrc.gov.cn/xxgk/zcfb/ghwb/202103/t20210323_1270124.html?code=&state=123

Needham J (1954). *Science and Civilisation in China*. Cambridge University Press. [UL-DS721.N39]
Referred to as *SCC*, Volume 5 therein as *SCC*5, Volume 5 Part 7 as *SCC*5-7 etc.
Free download from
https://archive.org/details/ScienceAndCivilisationInChina

Needham J (1969). *The Grand Titration: Science and Society in East and West*. Routledge, London. [UL-Q127.C5N42]
Online access through CUHK Library

Newton I (1687). *Philosophiae Naturalis Principia Mathematica.* A modern English version can be found in Newton I, Cohen I & Whitman A (1999). *The Principia: Mathematical principles of natural philosophy.* University of California Press, Berkeley [UL-QA803.N413].
An alternate source is also available online:
`https://en.wikisource.org/wiki/The_Mathematical_Principles_of_Natural_Philosophy_(1729)`

Nobel Foundation (2015). "The Nobel Prize in Physiology or Medicine 2015: Tu Youyou".
`https://www.nobelprize.org/prizes/medicine/2015/tu/facts/`

Pan Jiexing (2002). *Zhongguo Gudai Si Da Faming: Yuanliu, Waichuan ji Shijie Yingxiang* [*The Four Great Inventions of Ancient China: Their Origin, Development, Spread and Influence in the World*]. University of Science and Technology of China (USTC) Press. [UL-T27.C3P36]

People's Daily (1977). Editorial, 7 February 1977. See commentary at
`http://news.sohu.com/20090207/n262098935.shtml`

Peierls RE (1991). *More Surprises in Theoretical Physics.* Princeton University Press. [UL-QC20.P345]

Pilling D (2015). Book review on Tse (2015), in *Financial Times.*
`https://www.ft.com/content/a1542148-3543-11e5-b05b-b01debd57852`

Popkin RH (1966). *The Philosophy of the Sixteenth and Seventeenth Centuries.* The Free Press, New York.

Popper KR (1959). *The Logic of Scientific Discovery.* Revised edition (1968), Hutchinson, London. [UL-Q175.P863]

Qian Baocong (1964). *Zhongguo Shuxue Shi* (*A History of Chinese Mathematics*). Kexue Chuban She. [UL-QA27.C5]. Online version available through CUHK Library

Ren Hongjun (1915). "The reason why there is no science in China" (in Chinese). Kexue. Vol 1, number 1.
`http://www.bjb.cas.cn/tbzt2016/dnzt/sd/jdwz/202008/t20200811_5652538.html`

Ren Zhengfei (2020). Speech to leadership of C9 universities (in Chinese). Huawei official web.
`https://xinsheng.huawei.com/cn/index.php?app=forum&mod=Detail&act=index&id=5118751`

Ronan CA (1978). *The Shorter Science and Civilisation in China.* Cambridge, UK. [UL-DS 721.N392].
Also cited as *SSCC* and Volume 1 therein as *SSCC*1 etc.
This series is sometimes referred to under the authorship of Ronan and Needham.

Russell, B (1921). "China's road to freedom", in Philosophia, No. 3, pp 357–368, cited in Chow (1960, pp 234–235).

SCC. See Needham (1954).

Shen Kuo (1088). *Mengxi Bitan* (*Dream Pool Essays*). An annotated version of the Chinese original is available at [NA-PL2687.S5M4834]

Sivin N (2017). "The Needham question", in *Oxford Bibliographies*. DOI: 10.1093/OBO/9780199920082-0006
http://www.oxfordbibliographies.com/view/document/obo-9780199920082/obo-9780199920082-0006.xml

Sohu (2021). Sohu News. 19 April 2021. "Qiaoming matchstick factory: Seeing import of matchsticks causing outflow of money, our campatriot started a factory in Foshan" (in Chinese).
https://www.sohu.com/a/461664141_260616

Spence JD (2008). "Reply to Goodman (2008)". *New York Review of Books*.
https://www.nybooks.com/articles/2008/11/06/why-didnt-science-rise-in-china/

SSCC. See Ronan (1978).

State Council (2015). State Council dissemination of "Made in China 2025" (in Chinese).
http://www.scio.gov.cn/xwfbh/xwbfbh/wqfbh/37601/39571/xgzc39577/Document/1644483/1644483.htm}

Strategy& (n.d.) Book review on Tse (2010).
https://www.strategyand.pwc.com/gx/en/insights/books/the-china-strategy.html

Temple, R (1989). *The Genius of China: 3,000 Years of Science, Discovery, and Invention.* Simon & Schuster. [UL-Q127.C5T44]

Treaty of Nanking (1842)
https://china.usc.edu/treaty-nanjing-nanking-1842

Treaty of Versailles
https://www.foundingdocs.gov.au/resources/transcripts/cth10_doc_1919.pdf

Tse E (2010). *The China Strategy: Harnessing the Power of the World's Fastest-Growing Economy.* Booz and Co.

Tse E (2015). *China's Disruptors: How Alibaba, Xiaomi, Tencent, and Other Companies are Changing the Rules of Business.* Penguin.

Tse E (2019). "Decoding China's Innovations". Report.
http://www.edwardtseblog.com/view/decoding-chinas-innovations/

Unwin J & Farmer M (2021). "The top 10 countries with the largest wind energy capacity in 2021". Power Technology.
https://www.power-technology.com/features/wind-energy-by-country/

Winchester S (2008). *The Man Who Loved China: The Fantastic Story of the Eccentric Scientist Who Unlocked the Mysteries of the Middle Kingdom.* Harper. [UL-Q143.N44W56]

Woit P (2006). *Not Even Wrong: The Failure of String Theory and the Search for Unity in Physical Law.* Basic Books. [UL-QC794.6.S85W65]

World Bank (2021a). The World Bank. "Countries and economies", a database.
https://data.worldbank.org/country/

World Bank (2021b). Data on publications are cited in
https://data.worldbank.org/indicator/
IP.JRN.ARTC.SC?most_recent_value_desc=true

World Bank (2021c). Data on patents are cited in
https://data.worldbank.org/indicator/
IP.PAT.RESD?most_recent_value_desc=true

Wujing Zongyao (*The Consolidated Military Principles*).
https://ctext.org/wiki.pl?if=en&res=817018

Xu Jiecheng (2015). "Some reflections on the research work on synthesis of crystalline bovine insulin" (in Chinese). Chinese Bulletin of Life Sciences, Vol 27, 719
DOI: 10.13376/j.cbls/2015109

Yang CN (2021). Closing remarks at the symposium celebrating the centenary of CN Yang, 22 Sep 2021.

Yang CN & Shi Yu (2014). "CN Yang's new recollections about his days at Southwest Associated University" (in Chinese).
http://zhishifenzi.com/depth/character/11101.html

Yung Wing [Rong Hong] (1909). *My Life in China and America.* Henry Holt & Co.
https://archive.org/details/mylifeinchinaand027665mbp

Zhuangzi.
https://ctext.org/zhuangzi

Figure Captions

Figure 1. Solving for the square root by neglecting the small corner area.

Figure 2. Yang Hui's triangle for the combinatoric coefficients. In the West this is known as Pascal's triangle.

Figure 3. Proof of Pythagoras' theorem, based on the identity $(a+b)^2 = 4(ab/2) + c^2$.

Figure 4. Proof of Pythagoras' theorem, based on the identity $c^2 = 4(ab/2) + (a-b)^2$.

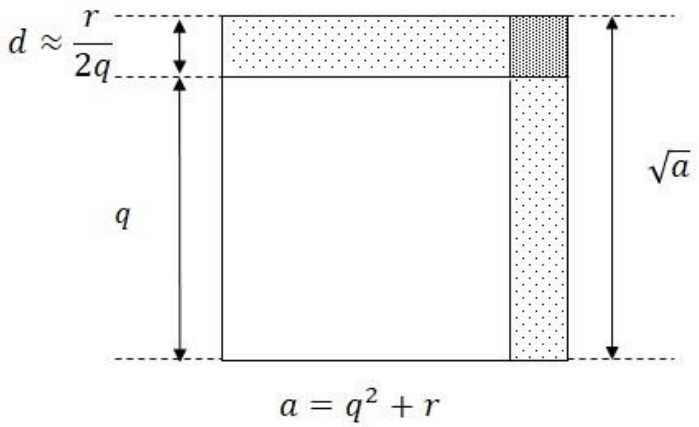
Figure 5. Proof of Pythagoras' theorem, based on the three triangles being similar and the areas proportional to the squares of the respective hypotenuses.

Figure 6. The perimeter of an inscribed hexagon gives a lower bound to 2π.

Figure 7. Different astronomical coordinate systems are defined by the choice of reference plane: either horizontal (H), ecliptic (E) or equatorial (Q).

Figure 8. Armillary spheres. Note that the base ring is tilted from the horizontal, by an angle that is the complement of the latitude.

Figures



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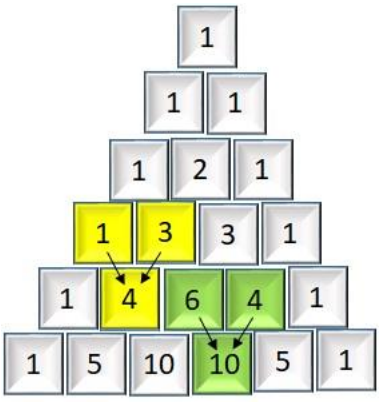

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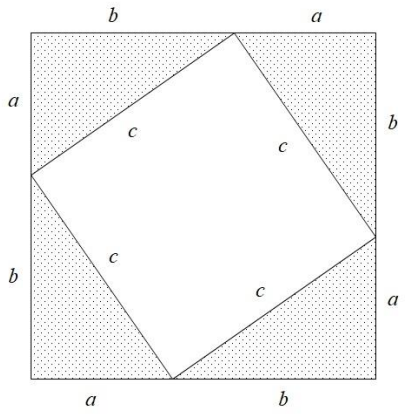

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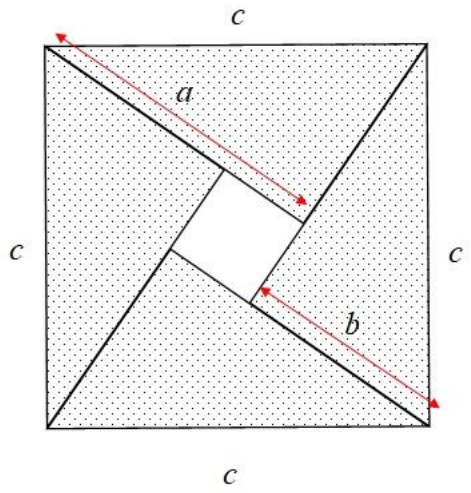

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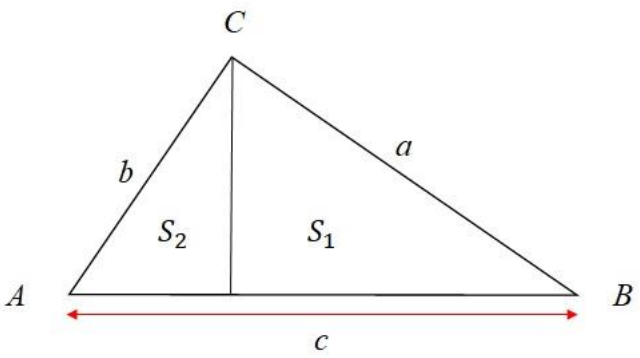

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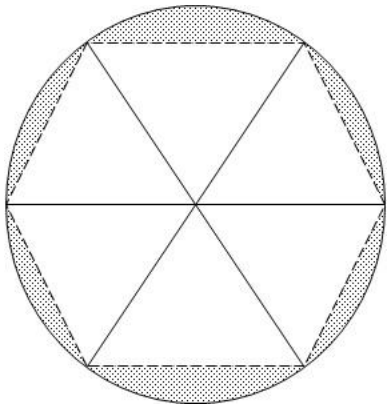

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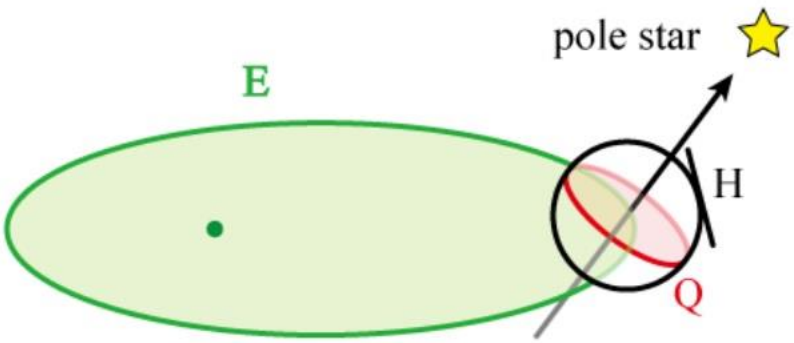

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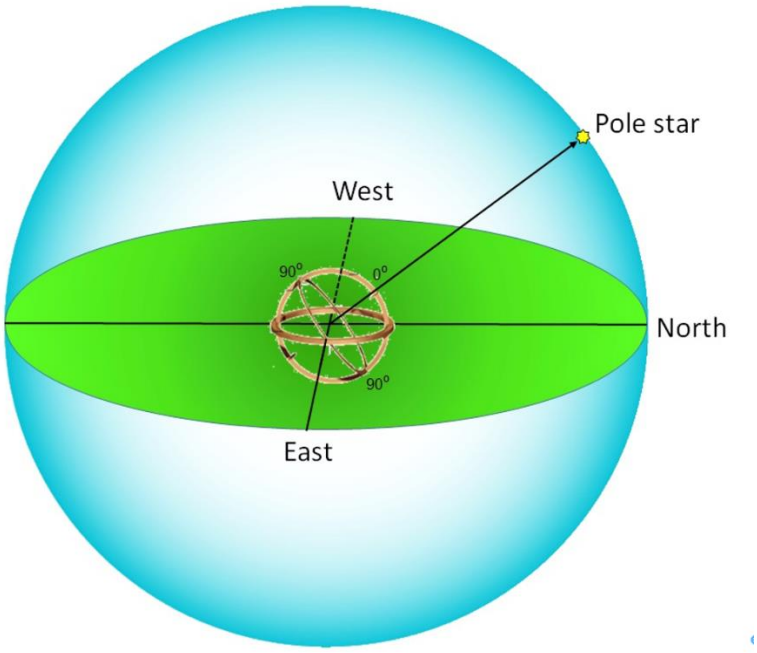

Figure 8. Armillary spheres. Note that the base ring is tilted from the horizontal by an angle that is the complement of the latitude.

Glossary

The Glossary is provided for names, terms and abbreviations that appear in the text in English, but may be more familiar (and would be more unambiguously identified) through the original names or terms in Chinese.

This Glossary also serves to cross-reference names that are rendered into English in more than one way. Please refer to Appendix A for the convention adopted as to the version regarded as primary. Before the standardisation of pinyin, given names (even for the "same" spelling) can in principle take four forms, e.g., Chow Tse Chung, Chow Tse-Chung, Chow Tse-chung, Chow Tsechung. Such alternatives are regarded as equivalent, and separate entries will not be recorded. In pinyin, the norm is to render the given name as a single word. Alternate forms that appear cross-referenced in the Glossary itself but not in the main text are in general not listed as separate entries, unless that form is widely known or commonly used.

Common words (as opposed to proper names) rendered into pinyin, regarded as non-English words in an English text, are set in italics. Italics is also used for names of books. For the sake of completeness, even "obvious" entries such as "Beijing" are also included. Some short explanatory remarks are also provided in a few cases.

A		
Anji	安濟	a bridge in Zhaozhou, Hebei
B		
Beida	北大	short form for Peking University (PKU) [1]
Beidou	北斗	Big Dipper, in *Ursa Major*
Beijing	北京	formerly Peking [2]
Beiyang	北洋	
Bi Sheng	畢昇	
C		
Cai Lun	蔡倫	
Cai Yuanpei	蔡元培	
Chan Man Hung	陳萬雄	see Chen Wanxiong
Chang'e	嫦娥	name of a series of missions to the Moon
chen	臣	minister (secondary medication)
Chen Duxiu	陳獨秀	
Chen Fangzheng	陳方正	see also Chen, FC
Chen, FC	陳方正	see Chen Fangzheng
Chen Shou	陳首	
Chen Wanxiong	陳萬雄	see also Chan Man Hung
Cheng Kaijia	程開甲	
Chern, SS	陳省身	
Chiang Kai Shek	蔣介石	see also Jiang Jieshi
Chongqing	重慶	

Chongzhen	崇禎	Ming Emperor
Chow Tse-tsung	周策縱	
Chu, CW	朱敬文	
Chu, MC	朱明中	
chuanjian paoli	船堅砲利	
Cixi	慈禧	Qing Empress Dowager
Conghua	從化	
CPC	中國共產黨	Communist Party of China [3]

D

Dalian	大連	
dan	丹	
Dao	道	
daodan	導彈	
Daodejing	道德經	
daojia	道家	
daojiao	道教	
Daxue	大學	one of the Four Books of Confucian Canon
Deng, Captain	鄧世昌	a captain in the Northern Fleet
Deng Jiaxian	鄧稼先	
Deng Xiaoping	鄧小平	
Ding, Commander	丁汝昌	commander of the Northern Fleet
Dongfanghong	東方紅	name of a (series of) satellite(s)

F

fa	法	as in Fajia 法家
Fajia	法家	Legalist
Feng Youlan	馮友蘭	
Foshan	佛山	
Fu Pu	傅溥	
fuxing	復興	rejuvenation (of the nation)
Fuzhou	福州	

G

gaitian	蓋天	a cosmological model
gaokao	高考	
Gengkuan	庚款	see Gengzi Peikuan [4]
Gengzi Peikuan	庚子賠款	Boxer Indemnity [4]
gewu	格物	
Gong, Prince	恭親王	
Gongsun Longzi	公孫龍子	also the title of his collected works
gou-gu-xian	勾股弦	
guandu minban	官督民辦	

Guangdong	廣東	
Guangming Ribao	光明日報	*Guangming Daily*
Guangxu	光緒	Qing Emperor
Guangzhou	廣州	
Guo Moruo	郭沫若	
Guo Yonghuai	郭永懷	
Guomindang	國民黨	see Kuomintang, KMT
guyu	穀雨	one of the solar terms

H

haigui	海歸	returned from abroad
Han	漢	the majority Chinese ethnic group
Han (Dynasty)	漢(朝)	
Han Fei	韓非	
Han Xin	韓信	
Hankou	漢口	
Hanlin Academy	翰林院	
Hanyang	漢陽	
Ho Sin Hang	何善衡	
Ho Tim	何添	
Ho-Leung-Ho-Lee	何梁何利	[5]
Hong Wansheng	洪萬生	also Horng Wann Sheng
Hu Shi	胡適	standard pinyin; see Hu Shih
Hu Shih	胡適	the form he himself used; see also Hu Shi
Hu Yaobang	胡耀邦	
Hua Guofeng	華國鋒	
Huainanzi	淮南子	also the title of his collected works
huntian	渾天	a cosmological model
huo	火	fire
huoyao	火藥	gun powder

J

Ji Aixue	季愛雪	
Jiawu	甲午	(war of) 1894
Jiang Jieshi	蔣介石	see Chiang Kai Shek
Jiang Qing	江青	
Jiangnan Arsenal	江南機器製造總局	
Jiangnan Shipyard	江南造船廠	
Jiangxi	江西	
Jiaotong (University)	交通(大學)	
jieqi	節氣	solar term(s)
jindaishi	近代史	modern history
jingshen	精神	spirit

Jingshi Daxuetang	京師大學堂	
jinshi	進士	
jun	君	sovereign (principal medication)

K

Kaifeng	開封	
Kang Youwei	康有為	
Kangxi	康熙	Qing emperor
ke	刻	Carve (typeface)
keji	科技	science and technology
Keji Ribao	科技日報	*Science and Technology Dail*y
kexue	科學	science, also the name of a journal
kexue jingshen	科學精神	scientific spirit
KMT	國民黨	see Kuomintang
Kunming	昆明	
Kuomintang	國民黨	KMT, also Guomindang

L

Laozi	老子	
Lau, L	劉遵義	Lawrence J Lau
Lee Quo-wei	利國偉	
Lee, TD	李政道	
Lee Teng-hui	李登輝	
Leung Kau Kui	梁鈤琚	
li	理	(principle of) rationality
Li Dazhao	李大釗	
Li Hongzhang	李鴻章	
Li Madou	利瑪竇	Matteo Ricci
Li Siguang	李四光	
Li Yan	李儼	
Li Ye	李冶	
Li Yuese	李約瑟	Joseph Needham
Liang Qichao	梁啟超	
liangdan yixing	兩彈一星	
liangzhi	良知	
Lin Zexu	林則徐	
Liu Hui	劉徽	
Liu Yadong	劉亞東	
lixue	理學	study of *li* (rationality)
Lo, Dennis	盧煜明	also Lo, YMD
Lowu	羅湖	pinyin would be Luohu
Lu Gwei-djen	魯桂珍	also Lu Gweizhen
Lu Gweizhen	魯桂珍	see Lu Gwei-djen

Lu Xun	魯迅	pen name of Zhou Shuren
Luk, KB	陸錦標	
Lunyu	論語	one of the Four Books of Confucian Canon
luopan	羅盤	

M

Ma Shijun	馬仕俊	
Maguan Treaty	馬關條約	Treaty of Shimonoseki
mangzhong	芒種	one of the solar terms
Mao Zedong	毛澤東	
Mengxi Bitan	夢溪筆談	*Dream Pool Essays*
Mengzi	孟子	also his work as one of the Four Books
Ming (Dynasty)	明(朝)	
Mingjia	名家	
Mo Di	墨翟	
Mozi	墨子	Master Mo Di

N

Nanjing	南京	
Nankai (University)	南開（大學）	
nian	年	year (between Chinese New Years)
Nie Rongzhen	聶榮臻	
Niu Jingyi	鈕經義	
Nong Shu	農書	
nongli	農曆	

P

Peking	北京	now Beijing [2]
Peking University	北京大學	See also Beida [1]
Peng Huanwu	彭桓武	
Pi Ch'iu (Building)	碧秋（樓）	

Q

qi	氣	
Qian Baocong	錢寶琮	
Qian Mu	錢穆	also Ch'ien Mu
Qian Sanqiang	錢三強	
Qian Xuesen	錢學森	
Qin (Dynasty)	秦(朝)	
Qin Jiushao	秦九韶	
Qingdao	青島	[6]
Qing (Dynasty)	清(朝)	
qinghaosu	青蒿素	artemisinin

R		
Ren Hongjun	任鴻雋	also HC Zen
Ren Zhengfei	任正非	
Rong Hong	容閎	see Yung Wing
S		
Shandong	山東	
Shanghai	上海	
Shen Kuo	沈括	sometimes Shen Gua
Shunzhi	順治	Qing emperor
Sichuan (University)	四川（大學）	
Song (Dynasty)	宋(朝)	
Su Buqing	蘇步青	
Su Song	蘇頌	
Suanjing	算經	*Principles of Mathematics*
sui	歲	year (between winter solstices)
Sun Yatsen	孫逸仙 、孫中山	in Chinese usually Sun Zhongshan 孫中山
Sunzi	孫子	Master Sun
Sunzi Suanjing	孫子算經	
T		
Tang Ruowang	湯若望	Adam Schall
tian yuan di fang	天圓地方	
Tiangong	天宮	name of space station
Tianguan	天關	*Zeta Tauri*
Tianjin	天津	
Tongzhi	同治	Qing emperor
Tse, Edward	謝祖墀	
Tsinghua (University)	清華（大學）	[7]
Tsingtao	青島	see Qingdao, [6]
tu	土	"earthy", or unsophisticated
Tu Youyou	屠呦呦	
W		
Wang Daheng	王大珩	
Wang Ganchang	王淦昌	
Wang Hongwen	王洪文	
Wang Yangming	王陽明	
Wang Yifang	王貽芳	
Wang Yinglai	王應睞	
Wang You	汪猷	
Wang Zhijiang	王之江	
Wang Zhuxi	王竹溪	

Wanli	萬曆	Ming emperor
Weizheng	為政	Chap 2 of *Lunyu*
Wu Dayou	吴大猷	Also TY Wu
Wuchang	武昌	
Wuhan	武漢	
Wujing Zongyao	武經總要	*The Consolidated Military Principles*
wuyuan	五院	Fifth Academy (under Ministry of Defence)

X

Xi Jinping	習近平	
Xian	西安	or properly Xi'an
Xianfeng	咸豐	Qing emperor
xiaokang	小康	moderate level of prosperity
xin	心	heart
Xin Qingnian	新青年	name of a journal, *New Youth*
Xinan Lianda	西南聯大	Southwest Associated University
xinxue	心學	
xiucai	秀才	
xixue wei yong	西學為用	
Xu Baolu	許寶騄	
Xu Guangqi	徐光啟	
xuanye	宣夜	a cosmological model
Xuanzang	玄奘	
Xujiahui	徐家匯	

Y

Yalu (River)	鴨綠江	
Yang Hui	楊輝	
Yang Fujia	楊福家	
Yang Wuzhi	楊武之	
Yang, CN	楊振寧	
yanghuo	洋火	matchstick
yangwu yundong	洋務運動	Self-Strengthening Movement
yao	藥	drug, medication
Yao Wenyuan	姚文元	
Ye Jianying	葉劍英	
Yihe Yuan	頤和園	
yihequan	義和拳	
Yu Min	于敏	
Yuan (Dynasty)	元(朝)	
Yuan Longping	袁隆平	
Yuan Shikai	袁世凱	
Yuanming Yuan	圓明園	

yuanzidan	原子彈	atom bomb
Yung, CT	容啟東	
Yung Wing	容閎	see also Rong Hong [8]
Yunnan	雲南	
yushui	雨水	one of the solar terms

Z

Zen, HC	任鴻雋	see Ren Hongjun
Zeng Guofan	曾國藩	
Zhan Tianyou	詹天佑	
Zhang Chunqiao	張春橋	
Zhang Qiujian	張邱建	
Zhang Zhidong	張之洞	
Zhang Zongsui	張宗遂	
Zhao	趙	[9]
Zhao Yuanren	趙元任	
Zhaoqing	肇慶	
Zhaoshangju	招商局	
Zhaozhou	趙州	a county in Hebei
Zhejiang	浙江	the province, and also the university (Zheda)
Zhen Luan	甄鸞	
Zheng He	鄭和	
Zhong Nanshan	鍾南山	
zhongxue wei ti	中學為體	
Zhongyong	中庸	one of the Four Books of Confucian Canon
Zhou Enlai	周恩來	
Zhou Guangzhao	周光召	
Zhou Peiyuan	周培源	
Zhou Shuren	周樹人	see Lu Xun
Zhoubi Suanjing	周髀算經	
zhu	鑄	cast (typeface)
Zhu De	朱德	
Zhu Guangya	朱光亞	
Zhu Lilan	朱麗蘭	
Zhu Xi	朱熹	
Zhuangzi	莊子	also his collected works
Zhuhai	珠海	
Zongli Yamen	總理衙門	
Zou Chenglu	鄒承魯	
Zu Chongzhi	祖沖之	
zuo	佐	adjutant (supplementary medication)
Zuo Zongtang	左宗棠	

Notes

[1] Although the city is now known as Beijing, the university retains its name in English as Peking University (abbreviated as PKU), not Beijing University. But the short form is Beida.
[2] Before uniform adoption of pinyin, the city would be known as Peking. The suffix "king" 京 means capital, so before 1949, the city was known as Peiping 北平.
[3] The correct term is CPC (Communist Party of China), not CCP (Chinese Communist Party).
[4] Strictly speaking, Gengzi Peikuan or Gengkuan means the indemnity. However, the term is also used informally to refer to the scholarship created out of the indemnity.
[5] Also see separate entries on Ho Sin Hang, Leung Kau Kui, Ho Tim and Lee Quo-wei
[6] The beer goes under the name Tsingtao.
[7] Standard pinyin should be Qinghua. However, the university has retained its historical name in English.
[8] The name Yung Wing was the one he himself adopted, romanized according to the Cantonese dialect. However, in standard Cantonese, his given name should be pronounced *wang4*.
[9] *The Orphan of Zhao* 趙氏孤兒大報仇 is the name of a play.